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10/34/WQPC-SWP
September 2010

Environmental Technology Verification Report

Coatings for Wastewater Collection Systems

Epoxytec, Inc.
Epoxytec CPP™ RC3

Prepared by

Center for Innovative Grouting Materials and Technology
University of Houston

For

NSF International

Under a Cooperative Agreement with
U.S. Environmental Protection Agency

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency | NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**Infrastructure Rehabilitation Technologies**	
APPLICATION:	**Coatings for Wastewater Collection Systems**	
TECHNOLOGY NAME:	**Epoxytec CPP RC3**	
TEST LOCATION:	**University of Houston, CIGMAT**	
COMPANY:	**Epoxytec International Inc.**	
ADDRESS:	**P.O. Box 3656**	**PHONE: 877-GO-EPOXY (463-7699)**
	West Park, FL 33083	**FAX: (954) 961-2395**
WEB SITE:	**http://www.epoxytec.com**	
EMAIL:	**ETV@epoxytec.com**	

The U.S. Environmental Protection Agency (EPA) created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The program's goal is to further environmental protection by accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholder groups, which consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests as appropriate, collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF), in cooperation with EPA, operates the Water Quality Protection Center (WQPC), one of six centers under the ETV Program. The WQPC recently evaluated the performance of the Epoxytec CPP™ concrete polymer paste for wastewater infrastructure protection and rehabilitation. The Epoxytec coating was tested at the University of Houston's Center for Innovative Grouting Materials and Technology (CIGMAT).

TECHNOLOGY DESCRIPTION

The following description of the Epoxytec CPP™ RC3 coating material (CPP) was provided by the vendor and does not represent verified information.

CPP is a two-component moisture sensitive, adhesive, chemical resistant, 100% solid strength epoxy paste that can be used as an adhesive, patching filler, or a protective high-build, stand-alone protective liner. CPP is designed to bond to concrete, steel, stone, wood, brick, and many other construction materials. The coating bonds vertically and overhead, and contains no solvents. Typical cure time for the coating is 12 hours.

VERIFICATION TESTING DESCRIPTION - METHODS AND PROCEDURES

The objective of this testing was to evaluate CPP used in wastewater collection systems to control the deterioration of concrete and clay infrastructure materials. Specific testing objectives were (1) to evaluate the acid resistance of CPP coated concrete specimens and clay bricks, both with and without holidays (small holes intentionally drilled through the coating and into the specimens to evaluate chemical resistance), and (2) determine the bonding strength of CPP to concrete and clay bricks.

Verification testing was conducted using relevant American Society for Testing and Materials (ASTM) and CIGMAT methods (ASTM[1] G20-88; C321-94; D4541-85 and CIGMAT[2] CT-1; CT-2; CT-3 respectively). Product characterization tests were conducted on the coating material and the uncoated concrete and clay specimens to assure uniformity prior to their use in the acid resistance and bonding strength tests. Epoxytec representatives were responsible for coating the concrete and clay specimens, under the guidance of CIGMAT staff members. The coated specimens were evaluated over the course of six months.

PERFORMANCE VERIFICATION

(a) Holiday Test - Chemical Resistance

CPP coated concrete cylinders and clay bricks were tested with and without holidays (small holes intentionally drilled through the coating) in deionized (DI) water and a 1% sulfuric acid solution (pH=1). A total of 20 coated concrete specimens and 20 coated clay brick specimens were exposed. Specimens were cured for two weeks prior to creation of 0.12 in. and 0.50 in. holidays. The 0.12 in. holidays were exposed to both DI water and acid solution, while the 0.50 in. holidays were exposed only to the acid solution. Observation of the specimens at 30 and 180 days was made for changes in appearance such as blistering or cracks in the coating around the holiday or color changes in the coating. Control tests were also performed using specimens with no holidays. A summary of the chemical exposure observations is presented in Table 1.

Table 1. Summary of Chemical Exposure Observations

Specimen Material (Coating Condition)	DI Water (days)				3% H_2SO_4 Solution (days)				Comments
	Without Holidays		With Holidays		Without Holidays		With Holidays		
	30	180	30	180	30	180	30	180	
Concrete – Dry	N (2)	N (2)	N (2)	N (2)	N (2)	N (2)	N (4)	N (4)	Color change in coating submerged in acid solution.
Concrete – Wet	N (2)	N (2)	N (2)	N (2)	N (2)	N (2)	N (4)	N (4)	Color change in coating submerged in acid solution.
Clay Brick – Dry	N (2)	N (2)	N (2)	N (2)	N (2)	N (2)	N (4)	N (4)	Color change in coating submerged in acid solution.
Clay Brick – Wet	N (2)	N (2)	N (2)	N (2)	N (2)	N (2)	N (4)	N (4)	Color change in coating submerged in acid solution.

N = No blister or crack; (n) = Number of specimens.

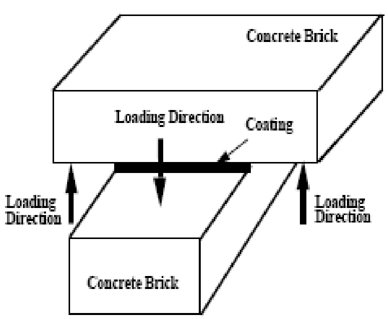
A specimen made only of CPP was submerged in water for 10 days, showing no weight change over the period. Likewise, over an exposure time of 180 days, weight changes in specimens with no holidays showed less than 0.25% gain in DI exposure and less than 0.45% in acid solution exposure. Without holidays, coated concrete specimens showed, 0.45% weight gain, while dry-coated clay bricks showed increases of 8-10% and wet-coated clay bricks showed 1.5-2.5% gains. Changes in the appearance of the specimens at the holiday levels were negligible after 180 days of exposure.

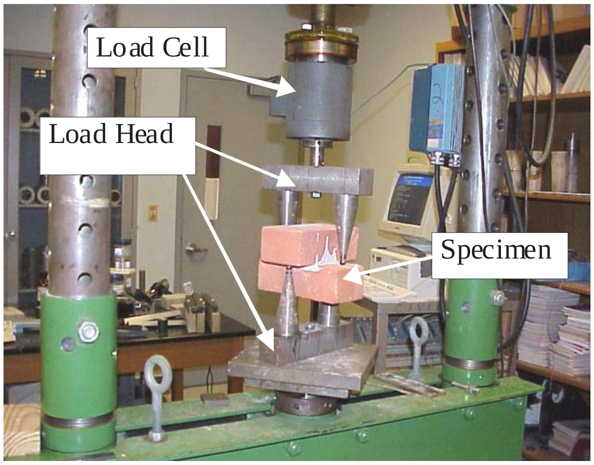
(b) Bonding Strength Tests (Sandwich Method and Pull-Off Method)

Bonding strength tests were performed to determine the bonding strength between the CPP coating and concrete/clay brick specimens over a period of six months. Eight sandwich (4 dry-condition, 4 wet-condition) and 16 pull-off (8 dry-condition, 8 wet-condition) tests were performed on both coated concrete samples and coated clay bricks.

Sandwich Test Method (CIGMAT CT 3)

CIGMAT CT 3, a modification of ASTM C321-94, was used for the testing. CPP was applied to form a sandwich between a like pair of rectangular specimens (Figure 1 (a)), both concrete brick and clay brick, and then tested for bonding strength and failure type following a curing period. The bonding strength of the coating was determined using a load frame (Figure 1 (b)) to determine the failure load and bonding strength (the failure load divided by the bonded area). The sandwich bonding tests were completed at 30, 90 and 180 days after application of the CPP.





(a) Test specimen configuration **(b) Load frame test setup**

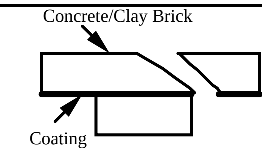
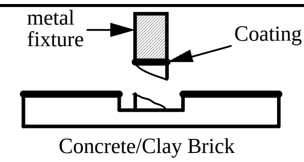
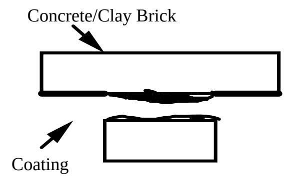
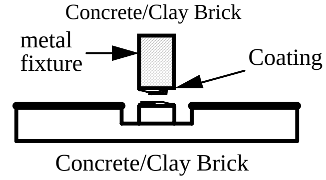
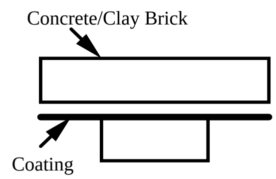
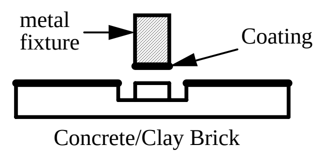
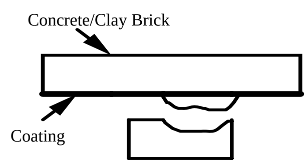
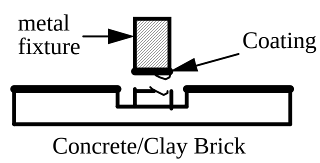
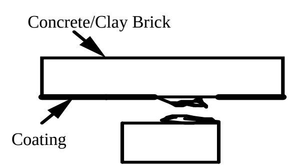
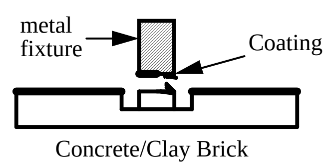
Figure 1. Bonding test arrangement for sandwich test.

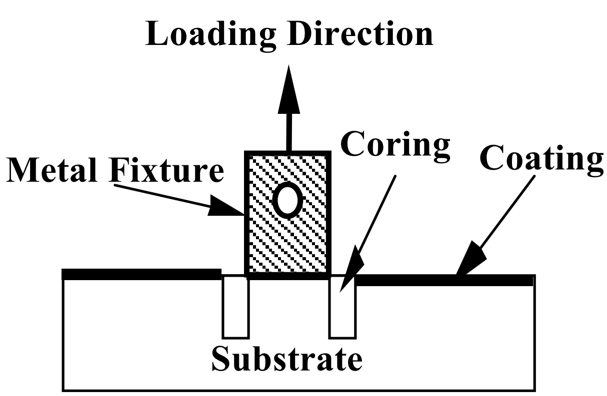
Dry-coated specimens were dried at room temperature conditions for at least seven days before they were coated, while wet-coated specimens were immersed in water for at least seven days before they were coated. Specimens were brush-cleaned before coating application. Bonded specimens were cured under water up to the point of testing. The type of failure was also characterized during the load testing, as described in Table 2.

Pull-Off Method (CIGMAT CT 2)

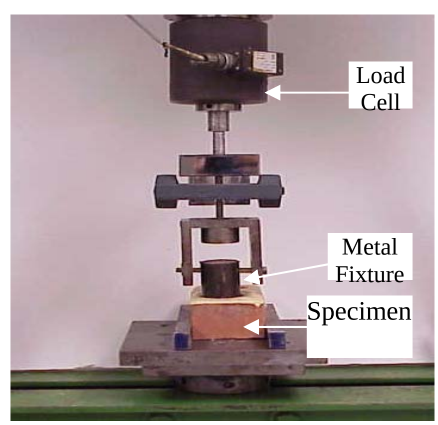
CIGMAT CT 2, a modification of ASTM D4541-85 was used for the testing. A 2-in. diameter circle was cut into coated concrete and clay bricks to a predetermined depth to isolate the coating, and a metal fixture was glued to the isolated coating section using a rapid setting epoxy.

Table 2. Failure Types in Sandwich and Pull-Off Tests

Failure Type	Description	Sandwich Test	Pull-Off Test
Type-1	Substrate Failure		
Type-2	Coating Failure		
Type-3	Bonding Failure		
Type-4	Bonding and Substrate Failure		
Type-5	Bonding and Coating Failure		



(a) Specimen preparation



(b) Load frame arrangement

Figure 2. Pull-off test method load frame arrangement.

Testing was completed on a load frame with the arrangements shown in Figure 2, with observation of the type of failure, as indicated in Table 2. The specimens were prepared in the same manner as for the sandwich test. The specimens were stored under water in plastic containers and the coatings were cored 24 hrs prior to the testing. The bonding tests were completed at 30, 60 and 180 days after application of the CPP. Results of the bonding tests are included in Table 3.

Table 3. Summary of Test Results for Bonding Strength Tests (12 Specimens for Each Condition)

Substrate – Application Condition	Test [1]	Failure Type [2] – Number of Failures					Failure Strength (psi)	
		1	2	3	4	5	Range	Average
Concrete – Dry	Sandwich	3			1		218 – 280	255
	Pull-off	8					153 – 235	190
Concrete – Wet	Sandwich					4	164 – 235	204
	Pull-off			8			92 – 236	142
Clay Brick – Dry	Sandwich	2				2	231 – 364	286
	Pull-off	8					190 – 284	251
Clay Brick – Wet	Sandwich	2				2	267 – 318	295
	Pull-off	6			2		184 – 342	282

[1]Sandwich Test (CIGMAT CT-2/Modified ASTM D 4541-85) or Pull-Off Test (CIGMAT CT-3/ASTM C 321-94).

[2]See Table 2.

(c) Summary of Verification Results

The performance of the Epoxytec, Inc. CPP Epoxy Coating for use in wastewater collection systems was evaluated for chemical resistance and the bond strength of the coating with both wet and dry substrate materials, made of concrete and clay brick. The type of bonding test, whether sandwich test or pull-off test, impact the mode of failure and bonding strength for both substrate materials. The testing indicated:

General Observations

- Samples of coating material showed no weight gain when exposed to water over a 10-day period.
- None of the coated concrete or clay brick specimens, with and without holidays, showed any indication of blisters or cracking during the six-month holiday-chemical resistance tests.
- There were no observed changes in the dimensions of coated concrete or clay brick specimens at the holiday levels for either DI or acid exposures.
- Two-thirds of all bonding tests (32 of 48) resulted in substrate (Type-1) and bonding/substrate (Type-4) failures.
- One-third of all bonding tests (16 of 48) resulted in bonding (Type-3) or bonding/coating (Type-5) failures.

Concrete Brick Substrate

- Weight gain was < 0.30% for any of the coated concrete specimens without holidays.
- Weight gain was <0.45% for wet or dry specimens with holidays for both water and acid exposures; no significant change with holiday size.
- Dry-coated concrete failures were mostly (11 of 12) concrete substrate (Type-1) failures, with one being a bonding and substrate (Type-4) failure.

- Average tensile bonding strength for dry-coated specimens was 212 psi, ranging from 153 to 280 psi.
- Wet-coated concrete failures were bonding and bonding/coating failures; eight of the 12 failures were bonding (Type-3) failures, with the remainder being bonding and coating (Type-5) failures.
- Average tensile bonding strength for wet-coated specimens was 163 psi, ranging from 92 to 236 psi.

<u>Clay Brick Substrate</u>

- Weight gain was < 0.45% for any of the coated clay brick specimens without holidays.
- Weight gain of 8-10% for dry-coated specimens with holidays for both water and acid exposures; 1.5-2.5% weight gain for wet-coated specimens with holidays for both water and acid exposures; no significant change for holiday size.
- Dry-coated clay brick failures were mostly (10 of 12) clay brick substrate (Type-1) failures, with two being a bonding and coating (Type-5) failures.
- Average tensile bonding strength for dry coated specimens was 262 psi, ranging from 190 to 309 psi.
- Wet-coated clay brick failures were predominantly (eight of 12) clay brick substrate (Type-1) failures, with two others being bonding and substrate (Type-4) and the remaining two being bonding and coating (Type-5) failures.
- Average tensile bonding strength with wet-coated specimens was 286 psi, ranging from 184 to 342 psi.

Quality Assurance/Quality Control

NSF completed a technical systems audit prior to the start of testing to ensure that CIGMAT was equipped to comply with the test plan. NSF also completed a data quality audit of at least 10% of the test data to ensure that the reported data represented the data generated during testing.

Original signed by
Sally Gutierrez *October 6, 2010*
Sally Gutierrez Date
Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Original signed by
Robert Ferguson *October 28, 2010*
Robert Ferguson Date
Vice President
Water Systems
NSF International

Availability of Supporting Documents

Referenced Documents:

1) Annual Book of ASTM Standards (1995), Vol. 06.01, Paints-Tests for Formulated Products and Applied Coatings, ASTM, Philadelphia, PA.
2) CIGMAT Laboratory Methods for Evaluating Coating Materials, available from the University of Houston, Center for Innovative Grouting Materials and Technology, Houston, TX.

Copies of the *Test Plan for Verification of Epoxytec International Epoxytec CPP Coating for Wastewater Collection Systems* (March 2009), the verification statement, and the verification report (NSF Report Number 10/34/WQPC-SWP) are available from:

ETV Water Quality Protection Center Program Manager (hard copy)
NSF International
P.O. Box 130140
Ann Arbor, Michigan 48113-0140

NSF website: http://www.nsf.org/etv (electronic copy)
EPA website: http://www.epa.gov/etv (electronic copy)

Environmental Technology Verification Report

Verification of Coatings for Rehabilitation of Wastewater Collection Systems

Epoxytec, Inc.

Prepared by

Center for Innovative Grouting Materials and Technology (CIGMAT)
University of Houston
Houston, TX 77204

Prepared for

NSF International
Ann Arbor, MI 48105

Under a cooperative agreement with the U.S. Environmental Protection Agency

Raymond Frederick, Project Officer
ETV Water Quality Protection Center
Water Supply and Water Resources Division
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Edison, New Jersey 08837

September 2010

NOTICE

The U.S. Environmental Protection Agency (USEPA) through its Office of Research and Development has financially supported and collaborated with NSF International (NSF) under a Cooperative Agreement. The Water Quality Protection Center, Source Water Protection area, operating under the Environmental Technology Verification (ETV) Program, supported this verification effort. This document has been peer reviewed and reviewed by NSF and USEPA and recommended for public release.

FOREWORD

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation’s land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA’s research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency’s center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory’s research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL’s research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory’s strategic long-term research plan. It is published and made available by EPA’s Office of Research and Development to assist the user community and to link researchers with their clients.

TABLE OF CONTENTS

FIGURES

TABLES

ACRONYMS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
CIGMAT	Center for Innovative Grouting Materials and Technology, University of Houston
°C	Celsius degrees
°F	Fahrenheit degrees
DI	Deionized (water)
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
ft/sec	Feet per second
ft^2	Square foot (feet)
holiday	A gap or void in the coating
hr	Hour(s)
in.	Inch(es)
kg	Kilogram(s)
L	Liter
lbs	Pounds
NRMRL	National Risk Management Research Laboratory
m^3	Cubic meters
mL	Milliliter(s)
mm	Millimeter(s)
MPa	MegaPascal(s)
NSF	NSF International
lb/ft^3	Pounds per cubic foot
psi	Pounds per square inch
QA	Quality assurance
QC	Quality control
Room conditions	23ºC ±2ºC and relative humidity of 50% ±5%
TO	Testing Organization
VO	Verification Organization (NSF)
VTP	Verification Test Plan
WQPC	Water Quality Protection Center

ACKNOWLEDGMENTS

EPA and NSF International acknowledge those persons who participated in the completion of the testing and preparation, review and approval of this Verification Report. Without their hard work and dedication to the project, this document would not have been approved through the process that has been set forth for this ETV project.

Thanks goes to Dr. C. Vipulanandan, Director of CIGMAT – Center for Innovative Grouting Materials and Technology, University of Houston for completion of the testing and preparation of the draft report. Thanks, too, to Mr. Dan Murray and Dr. John Schenk for technical review of the report, and to Mr. John Olszewski EPA QA Reviewer and Mr. Joe Terrell NSF QA Reviewer.

Special thanks to the Technical Panel Reviewers of the generic Coatings Test Plan, against which this testing was completed, including: Mr. Stephen A. Gilbreath, P.E. (Lockwood, Andrews & Newman, Inc.), Mr. Robert Lamb, P.E. (City of Austin, Texas) and Mr. Raghavender Nednur, P.E. (City of Houston, Texas).

SECTION 1
INTRODUCTION

1.1 ETV Purpose and Program Operation

The U.S. EPA created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The ETV Program's goal is to further environmental protection by substantially accelerating the acceptance and use of innovative, improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations (TOs); stakeholders groups that consist of buyers, vendor organizations, consulting engineers, and regulators; and the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

In cooperation with EPA, NSF operates the Water Quality Protection Center (WQPC), one of six centers under ETV. The WQPC has developed verification testing protocols and generic test plans that serve as templates for conducting verification tests for various technologies. Verification of the Epoxytec, Inc. Epoxy Coating CPP was completed following the Generic Test Plan for Verification of Coatings for Wastewater Collection Systems, 2008. The Generic Plan was used to develop a product-specific test plan for the CPP coating.

1.2 Roles and Responsibilities

The ETV testing of Epoxytec coating was a cooperative effort between the following participants:

- NSF International
- US EPA
- University of Houston – CIGMAT
- Epoxytec Inc.

1.2.1 *Verification Organization (NSF)*

The ETV Program’s WQPC is administered through a cooperative agreement between EPA and NSF. NSF is the verification partner organization for the WQPC and the SWP area within the center. NSF administers the Center and contracts with the Testing Organization (TO) to develop and implement the VTP, conduct the verification test, and prepare the verification report.

NSF's responsibilities as the VO included:

- Coordinate with CIGMAT, the TO, and the vendor to prepare and approve a product-specific test plan using this generic test plan as a template and meeting all testing requirements included herein;
- Coordinate with the ETV Coatings Technical Panel, as needed, to review the product-specific test plan prior to the initiation of verification testing;
- Coordinate with the EPA WQPC Project Officer to approve the product-specific verification test plan (VTP) prior to the initiation of verification testing;
- Review the quality systems of the testing organization and subsequently, qualify the TO;
- Oversee the coatings evaluations and associated laboratory testing;
- Review data generated during verification testing;
- Oversee the development of a verification report and verification statement;
- Print and distribute the verification report and verification statement; and
- Provide quality assurance oversight at all stages of the verification process.

Primary contact: Mr. Thomas Stevens
NSF International
789 North Dixboro Road
Ann Arbor, MI 48105
Phone: 734-769-5347
Email: stevenst@nsf.org

1.2.2 *U.S. Environmental Protection Agency (EPA)*

This verification report has been developed with financial and quality assurance assistance from the ETV Program, which is overseen by the EPA's Office of Research and Development (ORD). The ETV Program's Quality Assurance Manager and the WQPC Project Officer provided administrative, technical, and quality assurance guidance and oversight on all ETV WQPC activities. The primary responsibilities of EPA personnel were to:

- Review and approve VTPs, including the quality assurance project plans (QAPPs);
- Sign the VTP signoff sheet;
- Review and approve the verification report and verification statement; and
- Post the verification report and verification statement on the EPA ETV website.

Primary contact: Mr. Ray Frederick
Project Officer, Water Quality Protection Center
U.S. Environmental Protection Agency, NRMRL
2890 Woodbridge Ave. (MS-104)
Edison, New Jersey 08837
Phone: 732-321-6627
Email: frederick.ray@epamail.epa.gov

1.2.3 *Testing Organization (CIGMAT Laboratories at UH)*

The TO for this verification was CIGMAT Laboratories at the University of Houston. CIGMAT supports faculty, research fellows, research assistants and technicians. The CIGMAT personnel worked in groups to complete the tests described in this report. All personnel report to the Group Leader and the CIGMAT Director. The CIGMAT Director is responsible for appointing Group Leaders, who, with his approval, are responsible for drawing up the schedule for testing. Additionally, a Quality Assurance (QA) Engineer, who is independent of the testing program, was responsible for internal audits.

The primary responsibilities of the TO were:

- Coordinate with the VO and vendor to prepare and finalize the product-specific VTP;
- Sign the VTP signoff sheet;
- Conduct the technology verification in accordance with the VTP, with oversight by the VO;
- Analyze all samples collected during the technology verification process, in accordance with the procedures outlined in the VTP and referenced SOPs;
- Coordinate with and report to the VO during the technology verification process;
- Provide analytical results of the technology verification to the VO; and
- If necessary, document changes in plans for testing and analysis, and notify the VO of any and all such changes before changes are executed.

Primary contact: Dr. C. Vipulanandan (CIGMAT Director)
University of Houston, CIGMAT
4800 Calhoun
Houston, Texas 77004
Phone: 713-743-4278
Email: cvipulanandan@uh.edu

1.2.4 *Vendor (Epoxytec Inc.)*

The coating material being evaluated is marketed by Epoxytec Inc. The vendor was responsible for supplying the coating material and working with the TO in applying the coating to test specimens. Specific responsibilities of the vendor were:

- Complete a product data sheet prior to testing (refer to Appendix D);
- Provide the TO with coating samples for verification (this includes applying the coating materials to test specimens at the CIGMAT facilities);
- Sign the VTP signoff sheet;
- Provide start-up services and technical support as required during the period prior to the evaluation;
- Provide technical assistance to the TO during verification testing period as requested; and
- Provide funding for verification testing.

Primary contact: Mr. Demetri Rapanos
Epoxytec International Inc.
P.O Box 3656
West Park, FL 33083
Phone: 877-GO-EPOXY (463-7699)
Email: ETV@epoxytec.com

1.2.5 *Technology Panel*

A technology panel was formed to assist with the review of the generic coatings test plan. Input from the panel ensures that data generated during verification testing were relevant and that the method of evaluating different technologies is fair and consistent. The product-specific VTP was subjected to review by representatives of the technology panel and were approved by the WQPC Program Manager, the WQPC Project Officer, and the vendor.

1.3 Background and Technical Approach

University of Houston (UH)/CIGMAT researchers have been investigating the performance of various coatings for use in the City of Houston's wastewater facilities. Performance of each coating has been studied with wet (representing rehabilitation of existing wastewater collection systems) and dry (representing new construction) concrete and clay bricks. The studies have focused on:

- Applicability and performance of the coating under hydrostatic pressure (with an evaluation period between six to nine months);
- Chemical exposure with and without holidays (a gap or void in the coating) in the coating (initial evaluation period of six months); and
- Bonding strength (initial evaluation period of twelve months).

Chemical tests and bonding tests on over twenty coating materials are being continued at UH. The long-term data collected on each coating can further help engineers and owners to better understand the durability of coated materials in wastewater environments.

The overall objective of this testing program is to systematically evaluate coating materials used in wastewater systems to control the deterioration of cementitious materials using relevant ASTM and CIGMAT standards. Specimens made from the coating material, in addition to uncoated concrete and clay specimens, first undergo characterization testing to determine their suitability for use during acid resistance and bonding strength tests. Concrete and clay coated specimens are then evaluated over the course of six months.

1.4 Objectives

The objective of this study was to evaluate the Epoxytec International Inc. Epoxytec CPP™ (CPP) (dry and wet) for use in sewer rehabilitation projects. Specific objectives included:

- Evaluation of the acid resistance of the coated concrete and clay bricks with and without holidays; and
- Determination of the bonding strength of the coating materials to concrete and clay bricks over a period of time.

A coating-specific VTP was prepared for the Epoxytec coating material evaluated under this verification by the ETV Water Quality Protection Center (WQPC). The VTP included specific testing procedures and a quality assurance project plan (QAPP) describing the quality systems to be used during the evaluation

1.5 Test Facility

The testing was performed in the CIGMAT Laboratories at the University of Houston, Houston, Texas. The CIGMAT laboratories and affiliated facilities are equipped with devices that can perform all of the coatings tests. Molds are available to prepare the specimens for testing, and all acid resistance and bonding strength test procedures are documented in standard operating procedures.

SECTION 2
COATING DESCRIPTION

The coating material evaluated in this verification was the Epoxytec International Inc. Epoxytec CPP™ RC3 (CPP). The Vendor Data Sheet characterizing the coating material is included in Appendix D. The coating is described on the Epoxytec International Inc. web site (http://www.epoxytec.com/products/) as a concrete polymer paste used for structural concrete protection, rehabilitation and repair. Epoxytec's CPP is a 100% solid epoxy, designed to be applied by trowel. The CPP system is formulated to provide a structural liner, coating, or patch for rehabilitation of concrete and protection against corrosion.

The application instructions for the CPP were:

> Apply a maximum of 65 mils of the coating to protect concrete and clay bricks. No primer is used. The curing time for the coating is 12 hours. The coating is applied using a trowel.

The coating is gray in color, as shown in Figure 2-1 for a pure coating sample. Photos of the applied coating at the time of bonding tests are provided in Section 4.

Figure 2-1. Specimen of pure Epoxytec CPP.

SECTION 3
METHODS AND TEST PROCEDURES

The Verification Test Plan (VTP) includes a detailed description of the testing completed for the Epoxytec CPP. The testing involved characterization of the coating material, as well as holiday tests and bonding strength tests on the coated/lined specimens. The following is a summary of the methods and test procedures used in this verification.

3.1 Preparation of Test Specimens

Testing was completed using both concrete and clay brick specimens prepared in the CIGMAT laboratory by CIGMAT personnel prior to application of the coating. Concrete specimens were created by CIGMAT staff, while standard sewer clay bricks were obtained from a local brick supplier. Specimens were prepared to the proper specifications by CIGMAT staff.

3.1.1 *Preparation of the Concrete Specimens*

Cylindrical and prism concrete specimens were used during testing. Mix proportions for the concrete are summarized in Table 3-1. The cylindrical specimens were cast in 3-in. (diameter) × 6-in. (length) plastic molds, while wooden molds were used to cast the approximately 2.25-in. × 3.75-in. × 8-in. prism specimens.

Table 3-1. Mix Proportions for Concrete Specimens

Materials	Amount	Specification
Cement	6 bags	ASTM C150 Type 1 (purchased in 94 lb bags)
Sand	1400 -1500 lbs	ASTM C33
Coarse Aggregate	1600 -1700 lbs	ASTM C33 (ranging in size from No. 4 to 1.5 in. sieve)
Water	320 – 330 lbs	Tap water

Proper proportions of cement, sand, coarse aggregate and water were mixed in a concrete mixer until uniform in appearance. The molds were filled with the mixture and mechanically vibrated to the appropriate consistency. The specimens were cured for at least 28 days at room conditions (23ºC ± 2ºC and relative humidity of 50% ± 5%).

3.1.2 *Preparation of Clay Brick Specimens*

Standard sewer clay bricks used for the chemical exposure testing (holiday test) were cut approximately in half at the CIGMAT laboratory, resulting in specimens that are approximately 1-in. × 3.75-in. × 6-in. prism specimens using a diamond-tipped saw blade. The prepared specimens were stored at room conditions until use. Bonding tests were completed using whole clay bricks.

3.1.3 *Coating Specimens*

Specimens made of the Epoxytec CPP only were also prepared in 1.5-in. (diameter) × 3-in. (length) plastic molds. As indicated in Section 3.2, these specimens were analyzed and are reported to provide basic data that will be available to verify that the coating used in any future application is the same as applied for this verification testing.

3.2 Evaluation of Specimens

The concrete cylinders and prisms, clay brick prisms, and raw coating material cylinders were evaluated to determine their properties under the described test conditions. The specimens were characterized using the tests shown in Table 3-2.

Table 3-2. Test Names / Methods

Test Name	Test Method
Pulse Velocity	ASTM C 597
Holiday Test (Chemical Resistance)	ASTM G20 / CIGMAT CT-1-99
Bonding Strength	ASTM C 321/ CIGMAT CT-3 (Sandwich Method) ASTM D 4541/CIGMAT CT-2 (Pull-Off Strength)

The pulse velocity and unit weight of all the specimens were determined for quality control purposes. Additional specimens were used to determine the compressive (3 specimens) and flexural strength (3 specimens) of concrete and flexural strength of clay bricks (3 specimens) (Table 3-3). Note that the strength tests are done for completeness and not for quality control.

Table 3-3. Number of Specimens Used for Each Characterization Test

Material	Number of Specimens Used in Test				
	Unit weight	Pulse velocity (1)	Water absorption (2)	Flexure (3)	Compression (3)
Coating	6	6	6	N/A	N/A
Concrete Cylinders	20	20	10	N/A	2
Concrete Prisms	36	36	N/A	2	N/A
Clay Prisms	56	56	10	2	N/A

(1) Unit weight measurement taken on specimens prior to this test.
(2) Specimens used after the Pulse Velocity test.
(3) Flexure and compression tests are performed for informational purposes only.

3.3 Coating Application

The concrete and clay specimens were coated by a representative of Epoxytec Inc. in the CIGMAT laboratory at the University of Houston, in the presence of CIGMAT staff. Wet specimens were immersed in water for at least seven days before coating the specimens. All test specimens for the laboratory tests were prepared at the University of Houston Test Site over a period of three days. Prior to applying the coating, the surfaces of the concrete specimens were cleaned with a non-wire brush to remove laitance. The coating was applied directly to the specimen surfaces by trowel, with no primer prior to application as indicated by Epoxytec. The manufacturer recommends, in actual use, a single coat application up to 0.75 in. thickness. Per Epoxytec, the finished coating thickness was approximately 0.069 in. thick. This thickness was not verified by the TO, as the thickness of the applied coating does not impact the testing. The application temperature was 72º F (22º C) and humidity was typical of room conditions. Epoxytec indicates the minimum cure time before immersion into service is three hours at 77º F (25º C).

3.4 Evaluation of Coated Specimens

3.4.1 *Holiday Test (CIGMAT CT-1)*

The holiday test (CIGMAT CT-1, a modification of ASTM G20-88(2002)[1] used with concrete and clay brick materials) is a relatively rapid test to evaluate the acid resistance of coated concrete and clay brick specimens under anticipated service conditions. The test provides information about changes occurring to the specimens under two reagent conditions: (1) deionized (DI) water (pH = 5 to 6) and (2) 1% sulfuric acid solution (a pH of 1), which represents a long-term, worst-case condition in a wastewater collection system, arising from formation of hydrogen sulfide.

Changes in the specimens were monitored at regular intervals, including (1) diameter/dimension at the holiday level, (2) weight of the specimen, and (3) physical appearance of specimen. Control tests were also performed using specimens with no holidays.

Both wet and dry specimens were coated on all sides. As shown in Figure 3-1, two radial holidays of different diameters were drilled along the same axis into each specimen to a depth of approximately 0.125 in. The holiday diameters used during this test were 3 mm (0.125 in.) and 13 mm (0.50 in.). Specimens were cured for approximately 15 days prior to drilling the holes. This provided time to be sure the coating had sufficiently cured prior to the creation of the holidays so the physical action of the drill bits would not impact the integrity of the bond between the coating and the substrate at the location of the holiday. Half the specimen was submerged in the test liquid and half remained in the vapor space above the liquid. The specimens were stored at room temperature 74º F (23º C ± 2º C).

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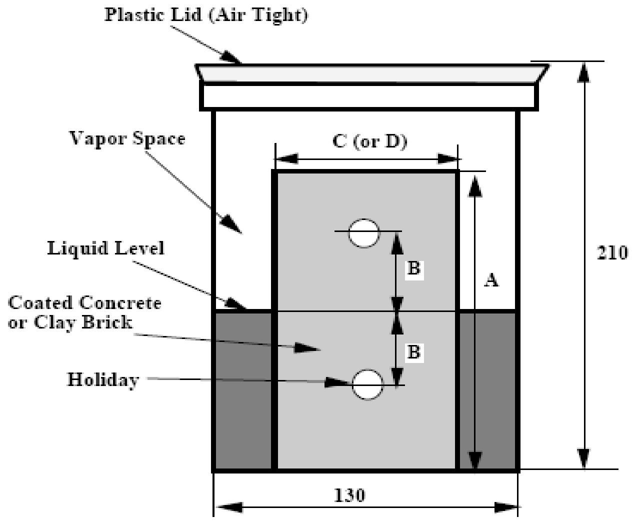
[1] American Society of Testing Materials (ASTM), "Standard Test Method for Chemical Resistance of Pipeline Coatings." ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959 USA



A ----- 152 mm (6.0 in.) height concrete specimen or clay brick
B ----- 38 mm (1.5 in.) holiday location
C ----- 76 mm (3 in.) diameter concrete cylinder
D ----- 152 x 64 x 45 mm cross section of clay brick

Figure 3-1. Test configuration for the holiday test.

The specimens were inspected after one and six months to determine if there were blisters, cracking of the coating, and/or erosion of the coating arising from the exposure. At the time of the inspections, the coated specimens were given ratings shown in Table 3-4.

Table 3-4. Ratings for Chemical Resistance Test Observations

Rating	Rating Notation	Observation
No significant change	N	No visible blister; no cracking.
Blister	B	Visible blister up to one inch in diameter; no cracking.
Cracking	C	Blister with diameter greater than one inch and/or cracking of coating at the holiday.

Further information regarding the chemical resistance testing, including a description of the coating failure mechanisms may be found at the following web site:

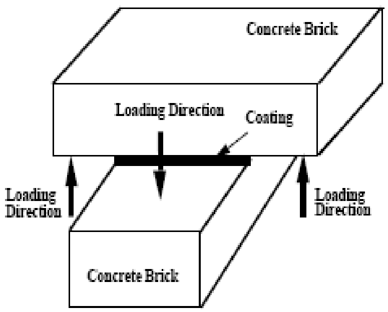
http://cigmat.cive.uh.edu/content/conf_exhib/99_poster/2.htm

3.4.2 *Bonding Strength Tests (Sandwich Method and Pull-Off Method)*

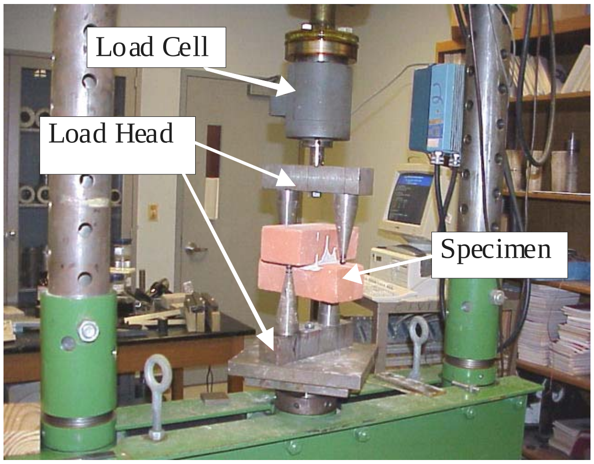
These tests are performed to determine the bonding strength between concrete/clay brick specimens and the coating material over a period of six months. Eight sandwich and twelve pull-off tests, for both dry and wet conditions, were performed on both coated concrete samples and coated clay bricks.

3.4.2.1 Sandwich Test Method (CIGMAT CT-3)

For this test (CIGMAT CT-3, a modification of ASTM C321-94[2]), the coating was applied to form a sandwich between a like pair of rectangular specimens (Figure 3-2 (a)), both concrete prisms and clay brick, and then tested for bonding strength and failure type following a curing period. The bonding strength of the coating was determined using a load frame (Figure 3-3 (b)) to determine the axial failure load, which is divided by the bonded area to determine the bonding strength.



(a) Test specimen configuration



(b) Load frame test setup

Figure 3-2. Bonding test arrangement for sandwich test.

Both dry and wet specimens were used to represent extreme coating conditions. Dry specimens were dried at room conditions for at least seven days before they were coated, while wet specimens were immersed in water for at least seven days before the specimens were coated. Bonded specimens were cured under water up to the point of testing. At the same time as the load testing, the type of failure was also characterized, as described in Table 3-5.

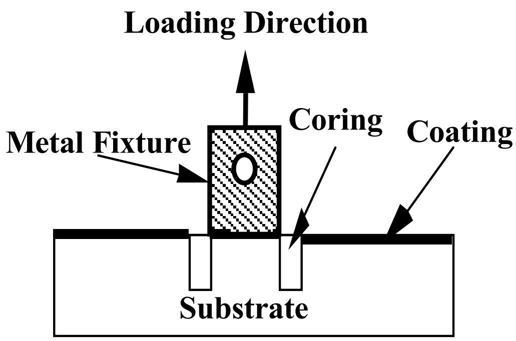
3.4.2.2 Pull-Off Method (CIGMAT CT-2)

For this test (CIGMAT CT-2, a modification of ASTM D4541[3]), a 2-in. diameter circle was cut into coated concrete prisms and clay bricks to a predetermined depth to isolate the coating, and a metal fixture was glued to the isolated coating section using a rapid setting epoxy. Testing was completed on a load frame with the arrangements shown in Figure 3-3, with observation of the type of failure, as indicated in Table 3-5. The specimens were prepared in the same manner as

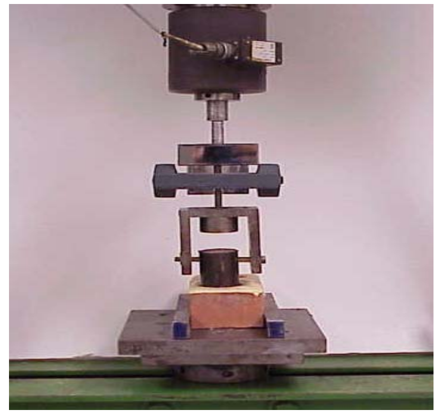
[2] American Society of Testing Materials (ASTM), "Standard Test Method for Bond Strength of Chemical-Resistant Mortars." ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959 USA

[3] American Society of Testing Materials (ASTM), "Standard Test for Pull-Off Strength of Coatings Using Portable Adhesion Testers." ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959 USA

for the sandwich test. The specimens were stored under water in plastic containers and the coatings were cored 24 hrs prior to the test.



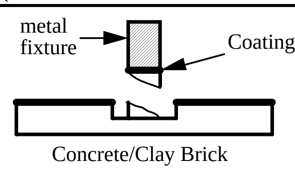
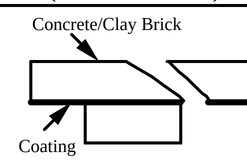
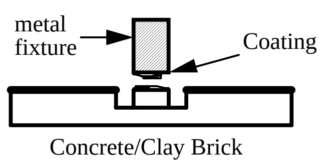
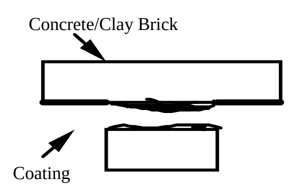
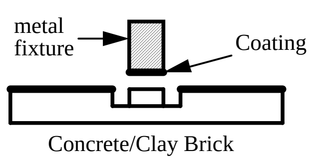
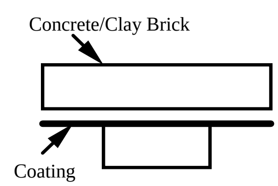
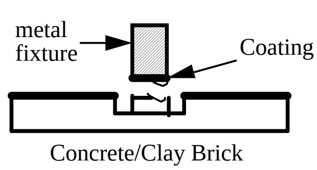
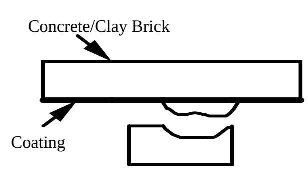
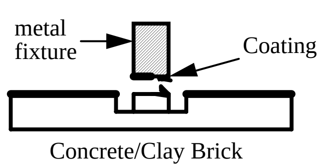
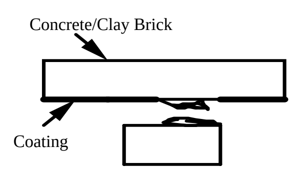
(a) Specimen preparation



(b) Load frame arrangement

Figure 3-3. Pull-off test method load frame arrangement.

Table 3-5. Failure Types in Pull-Off and Sandwich Tests

Failure Type	Description	CIGMAT CT 2 Test (Modified ASTM D4541)	CIGMAT CT 3 (ASTM C321)
Type-1	Substrate Failure		
Type-2	Coating Failure		
Type-3	Bonding Failure		
Type-4	Bonding and Substrate Failure		
Type-5	Bonding and Coating Failure		

A Type-1 failure is a substrate failure. This is the most desirable result if the bonding strength is quite high (in the range 8% to 12% of the concrete substrate compressive strength). In Type-2 failure, the coating has failed. Type-3 failure is a bonding failure where failure occurred between the coating and substrate. Type-4 and Type-5 are combined failures. Type-4 failure is a bonding and substrate failure where the failure occurs in the substrate and on the interface of the coating and the substrate. This indicates that the adhesive strength is comparable with the tensile strength of substrate. Type-5 failure is a coating and bonding failure where the failure occurs due to low cohesive and adhesive strength of the coating.

3.5 Testing Events

The frequency of testing events is summarized in Table 3-6. The timing of the coated sample testing was spaced so data would be obtained during an initial period (within the first 30 days), an intermediate period (three months) and long period (six months). It is not critical that the testing be completed at exactly 30 days, 90 days or 180 days, as the measurements provide an indication of any change in coating bonding over the six month period.

Table 3-6. Test Frequency

Approximate Exposure Times	Holiday Test*		Bonding Strength Test	
	DI Water	1% H_2SO_4	Sandwich	Pull-Off
30 days	20	20	8	16
90 days			4	8
180 days	20	20	4	8

* The same specimens are monitored for 180 days.

SECTION 4
RESULTS AND DISCUSSION

The testing was designed to evaluate the ability of the Epoxytec CPP coating (coating) to adhere to a substrate under varying conditions. Dry coating condition simulates a new concrete surface while wet condition simulates a rehabilitation condition. Adhesion was evaluated by three methods – introducing holidays in coated specimens to determine if exposure of the substrate to corrosive conditions impacts the bond of the coating to the substrate, determining the bond strength of the coating between two substrates, and determining the bond strength of the coating to a single substrate.

4.1 Test Results

4.1.1 *Coating Specimens*

Six specimens made only of the coating were evaluated for unit weight, pulse velocity and water absorption to provide basic data that will be available to verify that the coating used in any future application is the same as applied for this verification testing. The specimens were immersed in water for 10 days, showing no weight gain over the time frame. The unit weight varied from 62 lb/ft^3 (993 kg/m^3) to 68 lb/ft^3 (1089 kg/m^3) with an average of 65 lb/ft^3 (1041 kg/m^3) and a coefficient of variation of 1.9%. The pulse velocity varied from about 8660 ft/sec to about 8900 ft/sec, averaging about 8791 ft/sec with a standard deviation of 119 and a coefficient of variation of 1.3%. All data is provided in Table 4-1.

Table 4-1. Properties of Coating Samples (Epoxytec CPP™)

Specimen	Unit Weight (lb/ft^3)	Pulse Velocity (ft/sec)
1	67.5	8775
2	65.1	8674
3	65.4	8821
4	64.4	8985
5	63.7	8834
6	65.5	8661
Average	65.3	8791
Standard Deviation	1.28	119.4
Coefficient of Variation (COV)	1.9%	1.3%

4.1.2 *Coated Materials*

As stated in previous sections, the evaluation of the coating was accomplished in two phases – chemical resistance and bonding strength.

4.1.2.1 Holiday Test - Chemical Resistance

In order to evaluate the performance of CPP, coated concrete cylinders and clay bricks were tested with and without holidays in DI water and a 1% sulfuric acid solution (pH=1). Performance of CPP™ was evaluated over a period of six months, from March 2009 to September 2009, with monthly observations and measurements. A total of 20 coated concrete specimens and 20 coated clay brick specimens were exposed.

Specimen observations were made for physical changes in the coating and at the holidays, as well as specimen weight changes. The results of the physical observations are summarized in Table 4-2, with photographs of typical specimens shown in Figures 4-1 and 4-2. Detailed observations for all of the specimens are included in Appendix B.

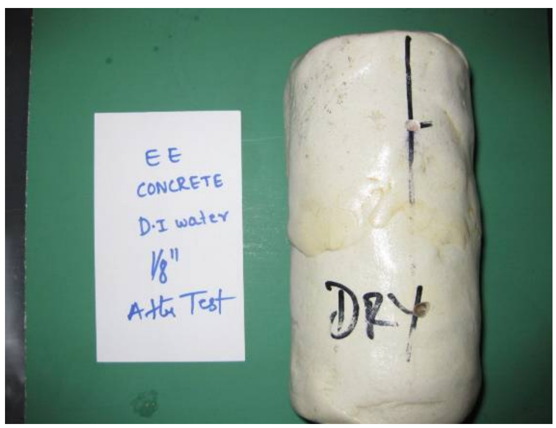


Figure 4-1. Concrete cylinder holiday specimen exposed to 1% H_2SO_4 solution.

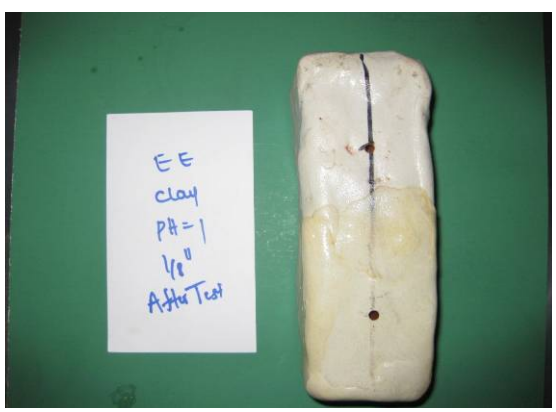


Figure 4-2. Clay brick holiday specimen exposed to 1% H_2SO_4 solution.

Table 4-2. Summary of Chemical Exposure Observations for Epoxytec, Inc. CPP

Specimen Material (Coating Condition)	DI Water				1% H_2SO_4 Solution				Comments
	Without Holidays		With Holidays		Without Holidays		With Holidays		
	30 days	180 days	30 days	180 days	30 days	180 days	30 days	180 days	
Concrete (Dry)	N (2)	N (2)	N (2)	N (2)	N (2)	N (2)	N (4)	N (4)	Coating color change noted in portion submerged in acid solution.
Concrete (Wet)	N (2)	N (2)	N (2)	N (2)	N (2)	N (2)	N (4)	N (4)	Coating color change noted in portion submerged in acid solution.
Clay Brick (Dry)	N (2)	N (2)	N (2)	N (2)	N (2)	N (2)	N (4)	N (4)	Coating color change noted in portion submerged in acid solution.
Clay Brick (Wet)	N (2)	N (2)	N (2)	N (2)	N (2)	N (2)	N (4)	N (4)	Coating color change noted in portion submerged in acid solution.

N = No blister or crack.

(n) = Number of observed specimens.

As noted in the observations in Appendix B, there was discoloration of the coating noted in the portion of the specimens submerged in the acid solution, with less discoloration in the portion of the specimens exposed to acid vapor. There was no discoloration noted for the water exposed specimens. Likewise, there were no observed changes in the dimensions of any of the specimens at the holiday level. Weight changes were also monitored for the specimens, as summarized in Table 4-3.

Table 4-3. Average Specimen Weight Gain (%) After 180 Days of Immersion

Specimen Type	Holiday	Dry-coated (% weight gain)		Wet-coated (% weight gain)	
		DI Water	H_2SO_4	DI Water	H_2SO_4
Concrete	None	0.12	0.11	0.25	0.18
	0.125 in.	0.24	0.35	0.30	0.27
	0.50 in.	-	0.44	-	0.34
Clay Brick	None	0.12	0.20	0.20	0.44
	0.125 in.	8.3	8.8	2.3	2.4
	0.50 in.	-	9.6	-	1.6

4.1.2.2 Bonding Strength

Bonding strengths of the Epoxytec CPP coating (dry and wet) with wet concrete and clay brick were determined according to CIGMAT CT-2 and CIGMAT CT-3 testing methods. All the coated specimens were cured under water. Both dry and wet concrete and clay brick specimens were coated to simulate the various field conditions. Performance of CPP Coating was evaluated starting with application of the coating on March 9, 2009. The first bonding tests were completed approximately three weeks after application, around March 28, 2009. The other tests completed around June 28, 2009 (three month samples) and September 28, 2009 (six month samples). A total of 24 bonding tests with concrete specimens and 24 with clay brick specimens were completed.

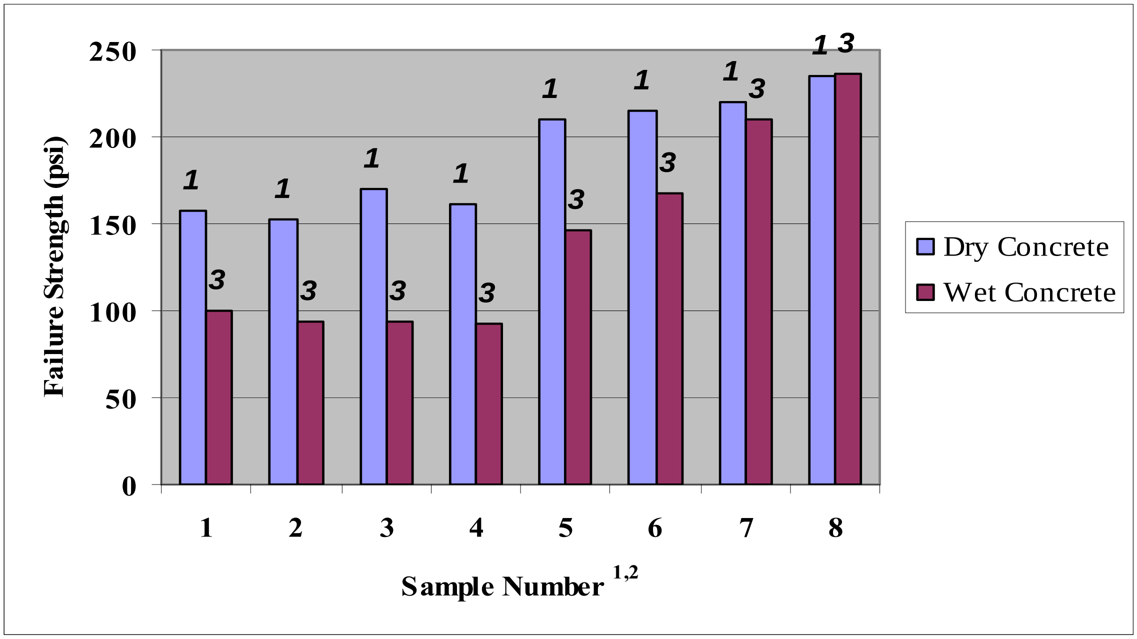
Two of the failure modes (Type-1 and Type-4) involved substrate failure, whether entirely or in association with a bonding failure, while the other three failure modes were associated with either bonding or coating failures, whether singly or in combination. The actual coating bonding strength for failures involving substrate was greater than indicated by the bonding strengths reported for Type-1 failures, as the bond of the coating exceeded the strength of the substrate (concrete or clay brick). Type-4 failures, which also involved substrate failure, were not as easily defined, as failure of the substrate could cause the coating to lose bond, or the loss of coating bond could result in a substrate failure.

The results for all bonding strength tests, both concrete and clay brick, are summarized in Table 4-4. Further detail of bonding strengths for concrete specimens, wet and dry, are presented in Figures 4-3 and 4-4, respectively. Bonding strength detail for dry and wet clay bricks are presented in Figures 4-5 and 4-6, respectively. Photographs of typical failures are shown in Figures 4-7 through 4-9. Detailed descriptions of the results are summarized in Appendix C.

Table 4-4. Summary of Test Results for Bonding Strength Tests

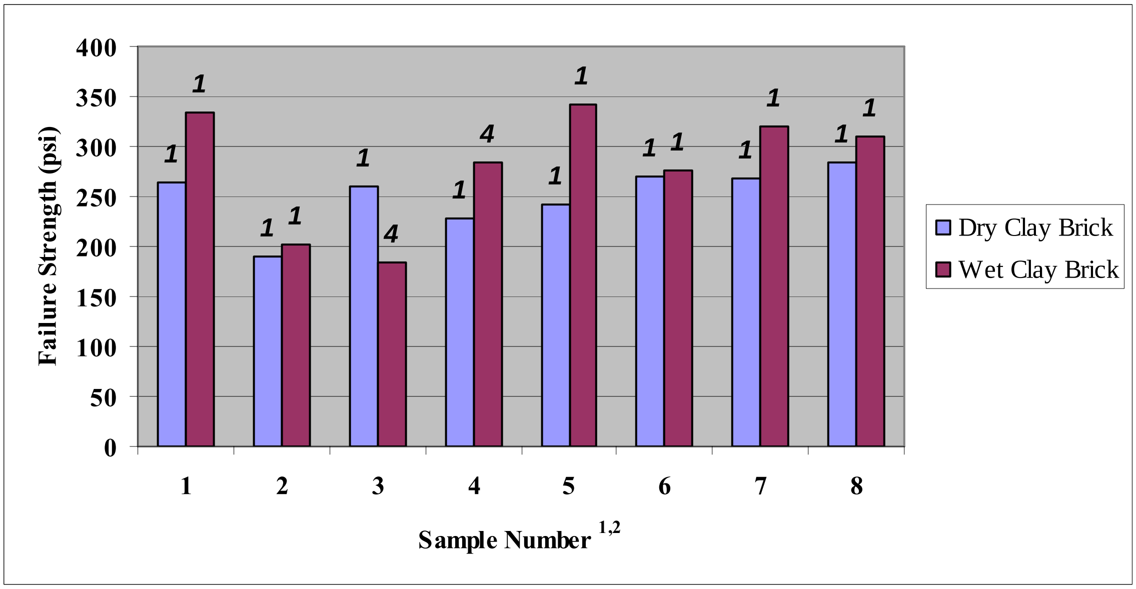
Substrate – Application Condition	Test [1]	Failure Type [2] – Number of Failures					Failure Strength (psi)	
		1	2	3	4	5	Range	Average
Concrete – Dry	Sandwich	3			1		218 – 280	255
	Pull-off	8					153 – 235	190
Concrete – Wet	Sandwich					4	164 – 235	204
	Pull-off			8			92 – 236	142
Clay Brick – Dry	Sandwich	2				2	231 – 364	286
	Pull-off	8					190 – 284	251
Clay Brick – Wet	Sandwich	2				2	267 – 318	295
	Pull-off	6			2		184 – 342	282

[1] Sandwich test (CIGMAT CT-3) or Pull-off test (CIGMAT CT-2).
[2] See Table 3-5.



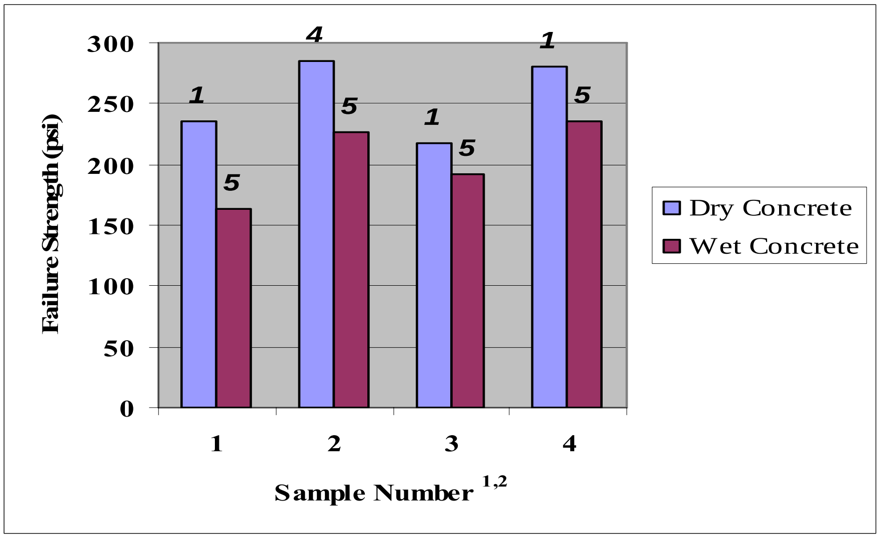
[1] Sample numbers 1 through 4 are 21-day breaks
Sample numbers 5 and 6 are 90-day breaks
Samples 7 and 8 are 180-day breaks
[2] ***Bold number*** above each column indicates Failure Type

Figure 4-3. Concrete bonding strength – pull-off test.



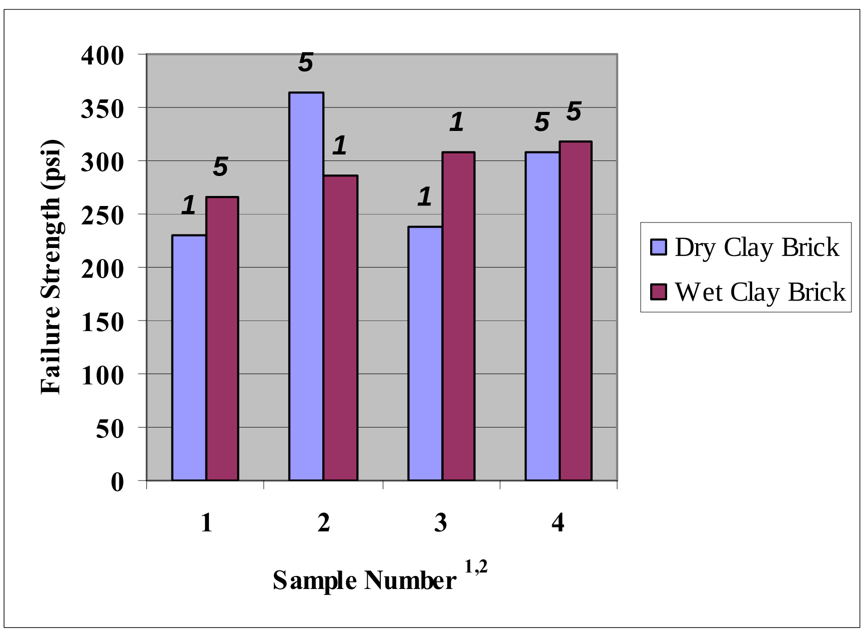
[1] Sample numbers 1 through 4 are 21-day breaks
Sample numbers 5 and 6 are 90-day breaks
Sample numbers 7 and 8 are 180-day breaks
[2] ***Bold number*** above each column indicates Failure Type

Figure 4-4. Clay brick bonding strength – pull-off test.



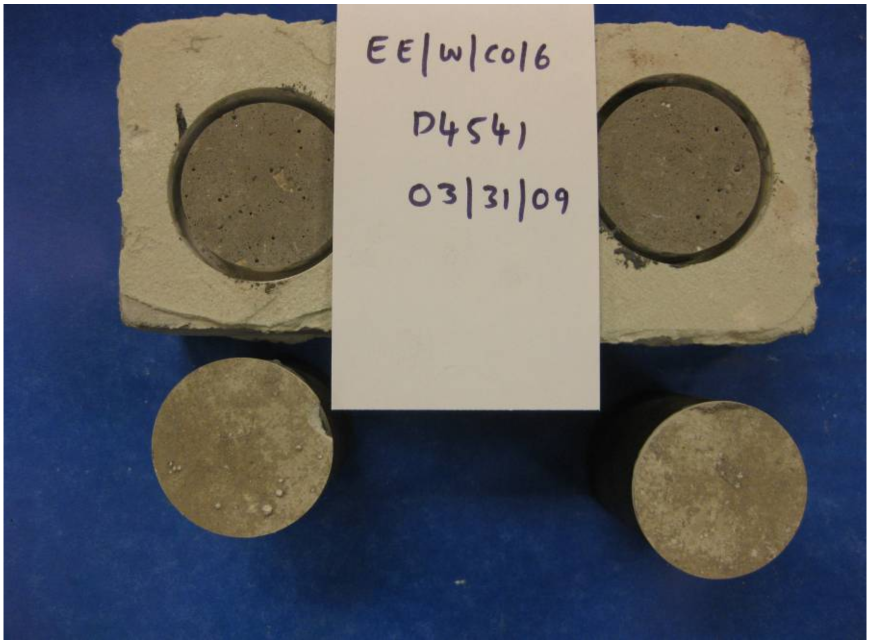
[1] Sample numbers 1 and 2 are 21-day breaks
Sample number 3 is the 90-day break
Sample number 4 is the 180-day break
[2] ***Bold number*** above each column indicates Failure Type

Figure 4-5. Concrete bonding strength – sandwich test.



[1] Sample numbers 1 and 2 are 21-day breaks
Sample number 3 is the 90-day break
Sample number 4 is the 180-day break
[2] ***Bold number*** above each column indicates Failure Type

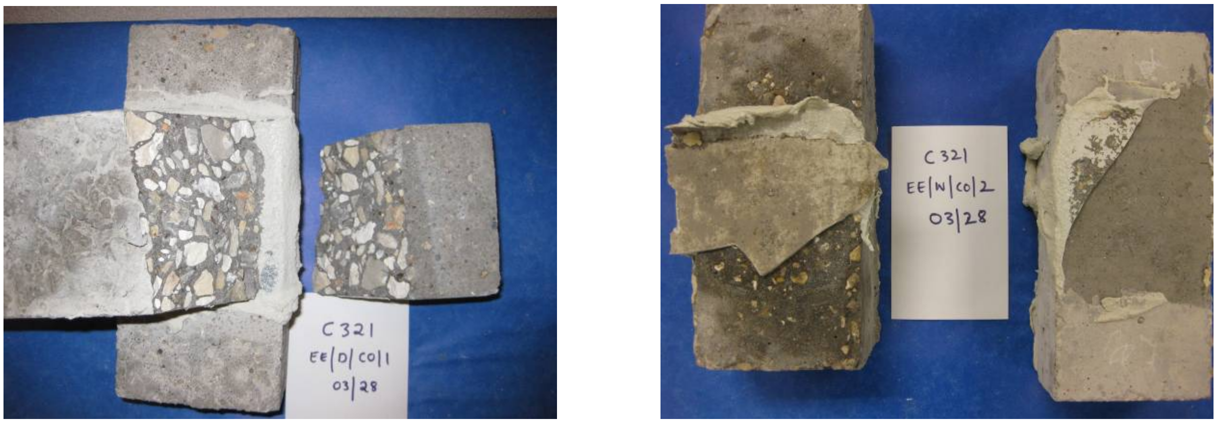
Figure 4-6. Clay brick bonding strength – sandwich test.



(a) Wet Concrete

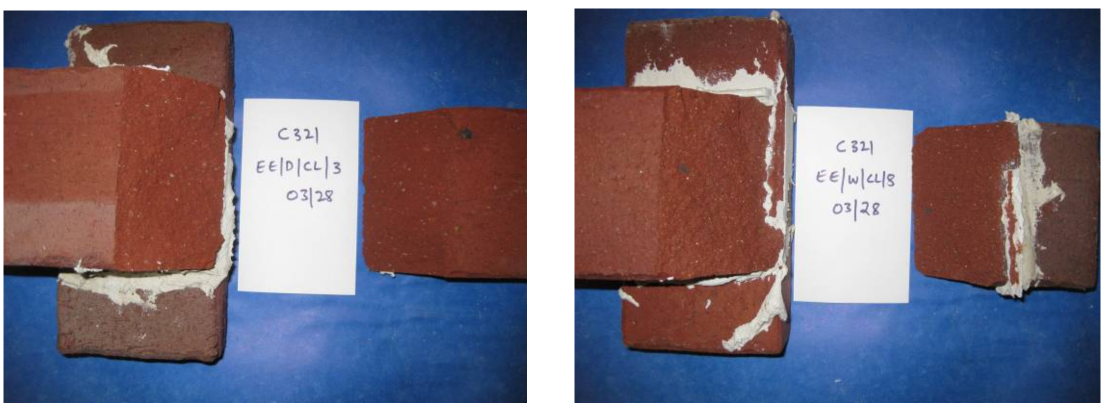
(b) Dry Concrete

Figure 4-7. Type-3 (a) and Type-1 (b) failure during CIGMAT CT-2 test with (a) wet and (b) dry concrete, respectively.



(a) Dry CPP coated concrete **(b) Wet CPP coated concrete**

Figure 4-8. Type-1 (a) and Type-5 (b) failures during CIGMAT CT-3 test – (a) dry-coated concrete and (b) wet-coated concrete.



(a) Dry CPP coated clay brick **(b) Wet CPP coated clay brick**

Figure 4-9. Bonding failure (Type-1 failure) during CIGMAT CT-3 test – (a) dry-coated clay brick and (b) wet-coated clay brick.

4.2 Summary of Observations

A combination of laboratory tests was used to evaluate the performance, over a six-month period, of Epoxytec, Inc. Epoxy Coating CPP (dry and wet) for coating concrete and clay bricks. The following observations are based on the testing results:

<u>General Observations</u>

- Specimens made only of the coating showed no weight gain when exposed to water over a 10-day period.

- None of the coated concrete or clay brick specimens, with and without holidays, showed any indication of blisters or cracking during the six-month holiday-chemical resistance tests.
- There were no observed changes in the dimensions of coated concrete or clay brick specimens at the holiday levels for either DI or acid exposures.
- Two-thirds of all bonding tests (32 of 48) resulted in Type-1 substrate (29) and Type-4 bonding/substrate (three) failures.
- One-third of all bonding tests (16 of 48) resulted in Type-3 bonding (eight) or bonding/coating (eight) failures.

Concrete Substrate

- Weight gain was < 0.30% for any of the coated concrete specimens without holidays.
- Weight gain was <0.45% for wet or dry specimens with holidays for both water and acid exposures; no significant change with holiday size.
- Dry-coated concrete failures were mostly (11 of 12) Type-1 substrate failures, with one being a Type-4 bonding/substrate failure.
- Average tensile bonding strength for dry-coated concrete specimens was 212 psi, with individual specimens ranging from 153 to 280 psi.
- Wet-coated concrete failures were bonding and bonding/coating failures; eight of the 12 failures were Type-3 bonding failures, with the remainder being Type-5 bonding/coating failures.
- Average tensile bonding strength for wet-coated concrete specimens was 163 psi, with individual specimens ranging from 92 to 236 psi.

Clay Brick Substrate

- Weight gain was < 0.45% for any of the coated clay brick specimens without holidays.
- Weight gain of 8-10% for dry-coated clay brick specimens with holidays for both water and acid exposures; 1.5-2.5% weight gain for wet-coated specimens with holiday for both water and acid exposures; no significant change for holiday size.
- Dry-coated clay brick failures were mostly (10 of 12) Type-1 substrate failures, with two being Type-5 bonding/coating failures.
- Average tensile bonding strength for dry-coated clay brick specimens was 262 psi, with individual specimens ranging from 190 to 364 psi.
- Wet-coated clay brick failures were predominantly (eight of 12) Type-1 substrate failures, with two being Type-4 bonding/substrate failures and the remaining two being Type-5 bonding/coating failures.
- Average tensile bonding strength with wet-coated clay brick was 286 psi, with individual specimens ranging from 184 to 342 psi.

SECTION 5
QA/QC RESULTS AND SUMMARY

The VTP included a Quality Assurance Project Plan (QAPP) that identified critical measurements for this verification. The verification test procedures and data collection followed the QAPP to ensure quality and integrity. The Center for Innovative Grouting Materials and Technology (CIGMAT) was primarily responsible for implementing the requirements of the QAPP during testing, with oversight from NSF.

The QAPP identified requirements for preparation of the concrete and clay brick specimens that would be coated and used during the verification, along with requirements for quality control indicators (representativeness, completeness and precision) and auditing.

5.1 Specimen Preparation

For each batch of concrete made at CIGMAT and clay bricks purchased to perform the laboratory tests, specimens were tested to be sure their properties were within allowable ranges. The tests included unit weight, pulse velocity and water absorption of the specimens. Flexural and compressive strengths were also measured, where appropriate, to characterize the specimens. The target values for the specimens were maximum or minimum value of the batch within $\pm$20% of the mean value of the batch. The property ranges for the different materials are summarized in Table 5-1.

Table 5-1. Typical Properties for Concrete and Clay Brick Specimens

Material	Unit Weight (lb/ft^3)	Pulse Velocity (ft/sec)	Strength (psi) Compressive	Strength (psi) Flexural	Water Absorption (%)
Concrete	117-172	12,700-15,800	4000-5000	900-1300	0.5-2
Clay Brick	132-153	8,500-10,250	NA	700-1200	18-30

5.1.1 *Unit Weight and Pulse Velocity*

5.1.1.1 Concrete

The pulse velocity and unit weight were determined for 20 concrete cylinders and 36 concrete prisms. The unit weight of the concrete cylinder specimens varied between 127 lb/ft^3 (2034 kg/m^3) and 150 lb/ft^3 (2403 kg/m^3), with a mean value of 144 lb/ft (2307 kg/m^3). The specimens all fell within the allowable $\pm$20% of the mean value of the batch. Pulse velocities ranged from 12,700 ft/sec to 15,800 ft/sec, with a mean of 13,600 ft/sec, within the allowable range of 20% of the mean value of the batch.

For the concrete block specimens, the unit weight varied between 117 lb/ft^3 (1874 kg/m^3) and 172 lb/ft^3 (2755 kg/m^3), with a mean value of 141 lb/ft^3 (2259 kg/m^3). The specimens all fell within the allowable $\pm$20% of the mean value of the batch. Pulse velocities ranged from 13,100 ft/sec to 15,200 ft/sec, with a mean of 13,700 ft/sec, within the allowable range of ±20% of the mean value of the batch.

There was no direct correlation between the pulse velocity and unit weight of concrete (Figure A1(a) in Appendix A). The variation of pulse velocity was normally distributed (Figure A1(b) in Appendix A).

5.1.1.2 Clay Brick

The unit weight and pulse velocity were determined on 56 clay brick specimens. The unit weight of clay brick specimens varied between 132 lb/ft^3 (2114 kg/m^3) and 153 lb/ft^3 (2451 kg/m^3), with a mean value of 138 lb/ft^3 (2211 kg/m^3) . The specimens all fell within the allowable $\pm$20% of the mean value of the batch.

The pulse velocity varied from 8,500 ft/sec to 10,250 ft/sec. There was no direct correlation between the pulse velocity and unit weight of clay bricks (Figure A2(a) in Appendix A). The variation of pulse velocity was normally distributed (Figure A2(b) in Appendix A).

5.1.2 *Water Absorption*

5.1.2.1 Concrete

The chemical resistance (DI water and an H_2SO_4 solution) of the concrete specimens was determined using one dry and one wet cylinder. The cylinders were partially submerged (50%) in the liquid solutions and each was weighed after 10, 30 and 60 days. The dry concrete cylinder partially submerged (50%) in water showed continuous increase in weight up to 0.4% in 60 days, while the wet concrete in water showed a 0.1% increase in weight in 60 days. Initially, within 30 days, the specimens showed a slight weight gain in the H_2SO_4 solution, but over 60 days a weight loss, with visible corrosion, was observed in both the dry and wet concrete specimens. The overall weight loss was about 0.5%. Results are summarized in Appendix A, Tables A1 and A2 for concrete cylinders dry and wet, respectively.

5.1.2.2 Clay Bricks

Dry bricks in both water and acid solutions showed similar weight gains of 13% and 15%, respectively, over the 60 days of exposure. Wet bricks showed much smaller weight gain compared with the dry bricks, with 0.4% and 0.5% gains for the water and acid exposures, respectively. Weight increase was not observed with further soaking. Results are summarized in Appendix A, Tables A3 and A4, for dry and wet clay brick, respectively.

5.1.3 *Compressive and Flexural Strength*

While not required by the VTP, compressive and flexural strengths were determined for the concrete and clay brick specimens, as appropriate. This information provides further assurance that the specimens are acceptable for this verification.

5.1.3.1 Concrete

Two specimens each of dry and wet concrete cylinders were tested for compressive strength, and two wet and two dry concrete block specimens were tested for flexural strength. All specimens were cured for 28 days. The average compressive strengths were about 5900 psi (41 MPa) for the wet concrete and about 4100 psi (28 MPa) for the dry cured concrete. The average flexural strength for the wet concrete was about 1100 psi (7.6 MPa) and was about 1200 psi (8.3 MPa) for the dry concrete. Compressive and flexural strength of dry and wet concrete are summarized in Table A5 in Appendix A.

5.1.3.2 Clay Brick

The average flexural strength was about 1100 psi (7.6 MPa) and about 930 psi (6.4 MPa) for wet and dry clay bricks, respectively. The flexural strength is important for bonding test CIGMAT CT-3 (Modified ASTM C321-94). The flexural strengths of the dry and wet clay bricks are summarized in Appendix A, Table A5.

5.2 Quality Control Indicators

5.2.1 *Representativeness*

Representativeness of the samples during this evaluation was addressed by CIGMAT personnel following consistent procedures in preparing specimens, having the vendor apply coatings to the specimens and following CIGMAT SOPs in curing and testing of the coated specimens.

5.2.2 *Completeness*

The numbers of substrate and coating specimens to be evaluated during preparation of the test specimens, as well as the number of coated specimens to be tested during the verification, were described in the VTP. The numbers that were completed during the verification testing are described in this section.

5.2.2.1 Specimen Preparation

The number (per the VTP) of each specimen to be used for characterization of the substrates is listed in Table 5-2. As there were multiple coatings being evaluated at the same time, CIGMAT prepared a batch of specimens to be coated in the tests. The number of specimens characterized during preparation of the batch of specimens is indicated in parentheses for each material and test listed in Table 5-2.

Table 5-2. Number of Specimens Used for Each Characterization Test

Material	Number of Specimens Used in Test [1]: Unit weight	Pulse velocity	Water absorption	Flexure [2]	Compression [2]
Coating	6 (6)	6 (6)	6 (6)	None	None
Concrete Cylinders	20 (102)	20 (18)	10 (10)	None	3 (2)
Concrete Prisms	36 (189)	36 (37)	None	3 (2)	None
Clay Prisms (Brick)	56 (159)	56 (18)	10 (10)	3 (2)	None

[1] n = Number of specimens to be characterized per VTP; (n) = Number of specimens observed or tested.

[2] Flexure and compression tests were performed for informational purposes only.

The number of specimens tested meet, or exceed the VTP requirement except for the pulse velocity for concrete cylinders and clay bricks. The unit weight of concrete is the most important parameter to determine the quality of the concrete, so every sample was tested for unit weight. The pulse velocity test, a special test not available for routine testing in test laboratories, was used at CIGMAT to randomly check the quality of the concrete. The pulse velocity test results on randomly selected concrete samples showed that there was nothing unusual about the concrete samples that were tested. As summarized in Appendix A, there was no direct correlation between the pulse velocity and unit weight of concrete, and the variation of pulse velocity was normally distributed.

The clay bricks obtained for testing were from the same batch. Quality control for the clay bricks involved both unit weight measurements and pulse velocity testing. The unit weight of each brick was determined, while the pulse velocity testing was completed on a random selection of bricks from the entire batch. The unit weights showed that there was nothing unusual (voids) in the specimens. The pulse velocity test was completed on 18 bricks (not the 56 indicated in the VTP). CIGMAT, based on their experience in testing with clay bricks, determined that the results of the 18 tests, combined with the unit weight data, were adequate to characterize the quality of the bricks. As summarized in Appendix A, there was no direct correlation between the pulse velocity and unit weight of clay bricks, and the variation of pulse velocity was normally distributed.

5.2.2.2 Coating Testing

The numbers (per the VTP) of coated specimens to be evaluated for each substrate during the testing are indicated in Table 5-3. The number of coated specimens was the same for each material (concrete or clay brick) and is indicated in parentheses in Table 5-3. The bonding tests were completed over a period of six months to determine if there are changes in bonding strength with time. Normally, the 3- and 6-month bonding test results did not differ much in failure type or bonding strength from the first tests (completed in the first 30 days), so additional specimens were evaluated at the initial test and fewer at later test times. The total number of specimens for the entire test was the same as indicated in the VTP.

Table 5-3. Total Number of Tests for Each Substrate Material

Exposure Time	Holiday Test [(1)]		Bonding Strength Test [(2)]	
	DI Water	1% H_2SO_4	Sandwich	Pull-Off
2 Weeks [(3)]			4 (4)	4 (8)
30 Days	8 (10)	12 (10)		
90 Days			4 (2)	4 (4)
180 Days	8 (10)	12 (10)	4 (2)	4 (4)

(1) The same specimens are monitored for 6 months.

(2) The number of dry- or wet-coated specimens is the same, and equal to half of the number indicated.

(3) The bonding tests were completed at 21 days during testing.

(n) = Number of specimens observed or tested.

5.2.3 *Precision*

As specified in Standard Methods (Method 1030 C), precision is specified by the standard deviation of the results of replicate analyses. The overall precision of a study includes the random errors involved in sampling as well as the errors in sample preparation and analysis. The VTP did not establish objectives for this measure.

In this evaluation, analysis is made using two different substrate materials (concrete and clay brick), each under two different conditions (dry-coated and wet-coated). Comparison of the results for multiple specimens prepared under similar conditions provides some indication of the variability of the bonding tests. For most of the bonding tests, there were only one or two specimens prepared and cured in the same manner and duration. The results for the 21-day pull-off tests, where there were four samples analyzed for each substrate and condition, are compared. The results are shown in Table 5-4.

Table 5-4. Standard Deviation for 21-Day Pull-Off Test

Substrate – Condition	Number of Samples	Average Failure Strength (psi)	Standard Deviation (psi)
Concrete – Dry	4	160	6.3
Concrete – Wet	4	95	3.0
Clay brick – Dry	4	236	29.9
Clay brick – Wet	4	251	60.8

5.3 Audit Reports

NSF conducted an audit of the CIGMAT Laboratory prior to the verification test. The laboratory audit found that CIGMAT had the necessary equipment, procedures, and facilities to perform the coatings verification test described in the VTP. Systems were in place to record laboratory data and supporting quality assurance data obtained during the tests. Specialized log sheets were prepared for each of the procedures and these data sheets were stored with the study Director, Dr. Vipulanandan. This is important as some of these tests were performed over several months with extended periods between testing. The primary weakness identified in the CIGMAT systems was in documentation of the calibration and maintenance of the basic equipment. It was quite clear that calibration of the balances, pH meters, pulse velocity meter, etc. was indeed performed. All of the needed calibration reference standards and standard materials were available near each piece of equipment. However, the frequency of calibration and the actual calibration could not be verified as in most cases the information was not being recorded either on the bench sheet or in an equipment calibration notebook. A corrective action recommendation was made by NSF following the audit. A second site visit for a data review meeting after the testing was completed indicated that CIGMAT instituted a system for recording calibrations during the testing period.

SECTION 6
REFERENCES

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APPENDIX A

Data from Evaluation of Pre-Coated Test Specimens and Coating

Behavior of Concrete Specimens, Clay Brick Specimens and Coating Summary

In order to ensure the quality of the evaluation, the concrete (cylinders and blocks) and clay bricks used in this study were tested and the results are summarized in this section. Also, specimens made entirely of the coating were analyzed to characterize the coating material.

A. 1. ***Unit Weight and Pulse Velocity***

To ensure the quality of the concrete and clay brick specimens used in this coating study the unit weight and pulse velocity of the specimens were measured. Six pure specimens of the coating were evaluated for unit weight, pulse velocity and water absorption to provide basic data that will be available to verify that the coating used in any future application is the same as applied for this verification testing.

Concrete: The variation of pulse velocity with unit weight is shown in Figure A1. The unit weight of concrete specimens varied between 117 lb/ft^3 (1874 kg/m^3) and 172 lb/ft^3 (2756 kg/m^3). The pulse velocity varied from 12,700 ft/sec to 15,800 ft/sec. There was no direct correlation between the pulse velocity and unit weight of concrete (Figure A1(a)). The variation of pulse velocity was normally distributed (Figure A1(b)).

Clay Brick: The variation of pulse velocity with unit weight is shown in Figure A2. The unit weight of clay brick specimens varied between 132 lb/ft^3 (2115 kg/m^3) and 153 lb/ft^3 (2451 kg/m^3). The pulse velocity varied from 8500 ft/sec to 10,250 ft/sec. There was no direct correlation between the pulse velocity and unit weight of clay bricks (Figure A2(a)). The variation of pulse velocity was normally distributed (Figure A2(b)).

Coating: The unit weight of coating varied from 63 lb/ft^3 to 68 lb/ft^3 with an average of 65 lb/ft^3 with a coefficient of variation of 1.9%. The pulse velocity varied from 8660 ft/sec to 8990 ft/sec with an average of 8791 ft/sec with a coefficient of variation of 1.3% (Table A6).

A. 2. ***Chemical Resistance***

Concrete: Results are summarized in Tables A1 and A2 for concrete cylinders dry and wet, respectively. Dry concrete cylinders partially submerged (50%) in water showed continuous increase in weight up to 0.4% in sixty days. The wet concrete in water showed a 0.1% increase in weight in 60 days. Weight loss and visible corrosion was observed in the dry and wet concrete specimens in the sulfuric acid solution (pH = 1).

Clay Bricks: Results are summarized in Tables A3 and A4 for dry and wet clay brick, respectively. Dry bricks in water and acids showed similar gain in weight of over 10%. No visible damage in bricks was observed. Wet bricks showed much smaller weight gain as compared to the dry bricks. Weight increase was not observed with further soaking.

Coating: Specimens immersed in water for 10 days showed no gain in weight.

A. 3. *Strength*

Concrete: Compressive and flexural strength of dry and wet concrete are summarized in Table A5. The minimum compressive strength of 28 days water cured concrete was 4100 psi (28 MPa) and the flexural strength was 1065 psi (7.6 MPa).

Clay Brick: Flexural strength of dry and wet clay bricks are summarized in Table A5. The average flexural strength was 1136 psi and 932 psi for wet dry and wet clay bricks. The flexural strength is important for bonding test CIGMAT CT-3 (Modified ASTM C321-94).

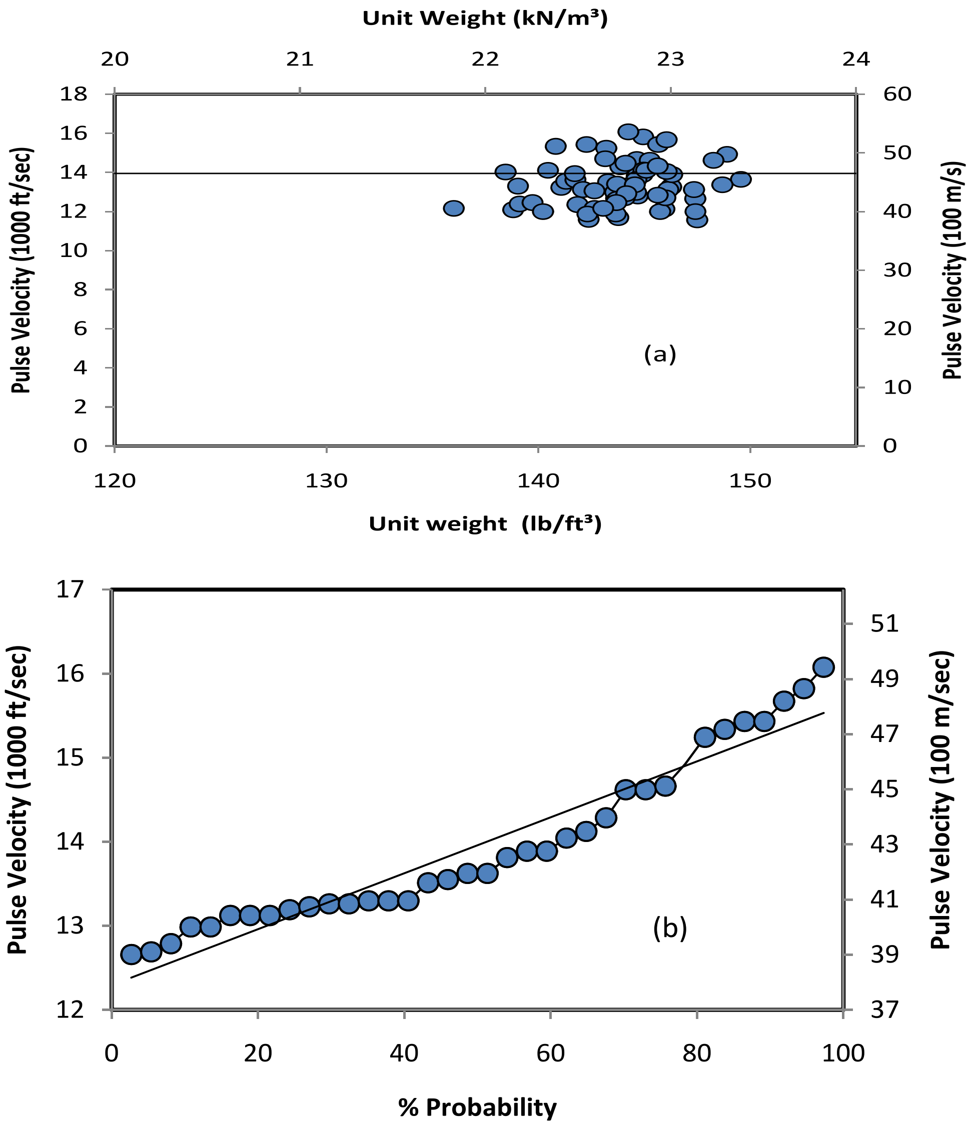


Figure A1. Quality control for concrete brick specimens (a) pulse velocity versus unit weight and (b) distribution of pulse velocity.

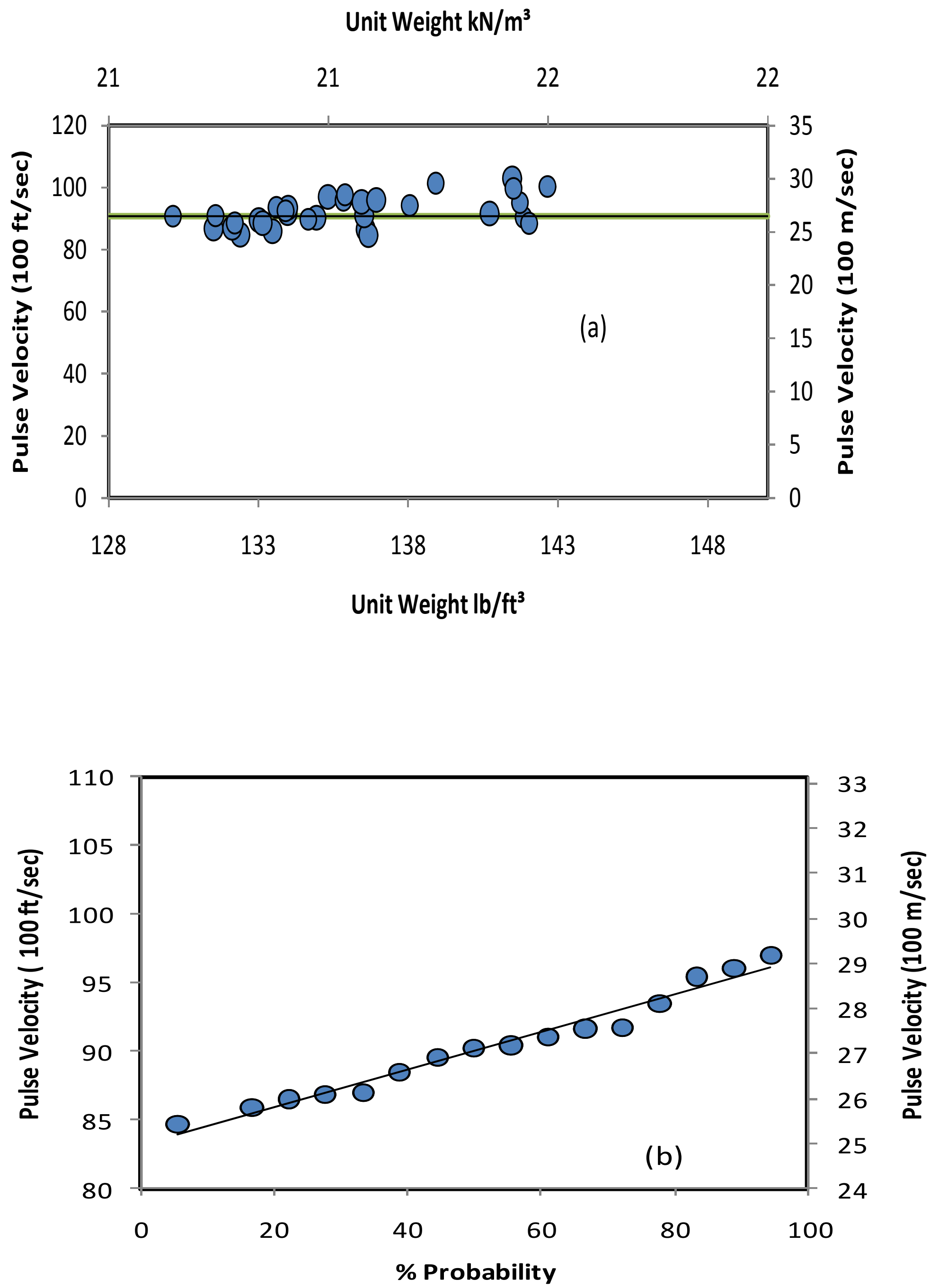


Figure A2. Quality control for clay brick specimens (a) pulse velocity versus unit weight and (b) distribution of pulse velocity.

Table A1. Results from Chemical Attack Test* on Dry Concrete (CIGMAT CT-1: No Holiday)

Concrete	Immersion Time (days)	Weight Change (%)		Remarks
		DI Water (pH= 6)	H_2SO_4 Solution (pH = 1)	
Dry	10	0.14	0.12	Similar weight change
	30	0.27	0.32	Similar weight change
	60	0.38	-0.48	Weight loss in acid solution
Remarks	Tested up to 2 months	Total weight change is 0.38 %	Total weight change is - 0.48%	Weight loss in H_2SO_4 solution in 60 days indicates the corrosivity

*50 % of specimen was submerged in liquid.

Table A2. Results from Chemical Attack Test* on Wet Concrete (CIGMAT CT-1: No Holiday)

Concrete	Immersion Time (days)	Weight Change (%)		Remarks
		DI Water (pH= 6)	H_2SO_4 Solution (pH = 1)	
Wet	10	0.06	0.11	Less weight gain in water
	30	0.09	0.31	Less weight gain in water
	60	0.11	-0.52	Weight loss in acid solution
Remarks	Tested up to 2 months	Total weight change is 0.11 %	Total weight change is -0.52 %	Weight loss in H_2SO_4 solution in 60 days indicates the corrosivity

*50 % of specimen was submerged in liquid.

Table A3. Results from Chemical Attack Test* on Dry Clay (CIGMAT CT-1: No Holiday)

Clay Brick	Immersion Time (days)	Weight Change (%)		Remarks
		DI Water (pH= 6)	H_2SO_4 Solution (pH = 1)	
Dry	10	9.9	9.0	Similar weight change
	30	13.6	15.6	Similar weight change
	60	14.9	17.6	Similar weight change
Remarks		Total weight change is 15 %	Total weight change is 18 %	Similar weight change in water and acid solution

*50 % of specimen was submerged in liquid.

Table A4. Results from Chemical Attack Test* on Wet Clay (CIGMAT CT-1: No Holiday)

Clay Brick	Immersion Time (days)	Weight Change (%)		Remarks
		DI Water (pH= 6)	H_2SO_4 Solution (pH = 1)	
Wet	10	0.18	0.25	Similar weight change
	30	0.32	0.43	Similar weight change
	60	0.40	0.52	Similar weight change
Remarks		Total weight change is 0.4 %	Total weight change is 0.52 %	Similar weight change in water and acid solution

*50 % of specimen was submerged in liquid.

Table A5. Average Strengths of Concrete Cylinders, Blocks and Clay Bricks

Materials	Curing Time (days)	Compressive Strength (psi)		Flexural Strength (psi)	
		Wet	Dry	Wet	Dry
Concrete Cylinder (No. Specimens)	28	5893 (2)	4099 (2)	N/A	N/A
Concrete Block (No. Specimens)	28	N/A	N/A	1065 (2)	1167 (2)
Clay Brick (No. Specimens)	N/A	N/A	N/A	1136 (2)	932 (2)
Remarks	Concrete cured for 28 days	Information for quality control	Information for quality control	Related to ASTM C321-94 bonding test	Related to ASTM C321-94 bonding test

APPENDIX B

Test Results and Observations from Chemical Exposure – Holiday Test

Laboratory Test: Holiday Test
(CIGMAT CT-1 (Modified ASTM G 20-88))

Summary: Sulfuric Acid Resistance

In order to evaluate the performance of CPP, coated concrete cylinders and clay bricks were tested with and without holidays in water and sulfuric acid solution (pH=1). Performance of CPP was evaluated over a period of six months from March 2009 to September 2009 in this study. A total of 20 coated concrete specimens and 20 coated clay brick specimens were tested. The results are summarized in Tables B1 through B6.

CPP (Dry-coated)
<u>(i) Concrete</u>

One month (30 days): None of the specimens showed blisters or cracking. Mild change in color of the coating was observed in the portion of the specimens submerged in sulfuric acid solution (Table B.1).

Six months (180 days): None of the specimens showed blisters or cracking. Discoloration (notable change) was observed in the lower part of the specimens (liquid phase) and partially in the upper part of the specimens (vapor phase), immersed in sulfuric acid solution (Table B.3).

<u>(ii) Clay Brick</u>

One month (30 days): None of the specimens showed blisters or cracking. Mild change in color of the coating was observed in the portion of the specimens submerged in sulfuric acid solutions.

Six months (180 days): None of the specimens showed blisters or cracking. Discoloration was observed on the portion of the specimens submerged in sulfuric acid solutions.

CPP (Wet-coated)
<u>(i) Concrete</u>

One month (30 days): None of the specimens showed blisters or cracking. Minor change in color of the coating was observed in the portion of the specimens submerged in sulfuric acid (Table B.2).

Six months (180 days): None of the specimens showed blisters or cracking. Discoloration was observed, in the lower part of the specimens (liquid phase) and partially in the upper part of the specimens (vapor phase), immersed in sulfuric acid solution (Table B.4).

(ii) Clay Brick

One month (30 days): None of the specimens showed blisters or cracking. Minor change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solutions.

Six months (180 days): None of the specimens showed blisters or cracking. Discoloration was observed on the portion of the specimens submerged in sulfuric acid solutions.

Rating Criteria for Holiday Test Results

No Blister or Cracking (N): No visible blister. No discoloration. No cracking.
Blister (B): Visible blister up to one inch in diameter. No discoloration. No cracking.
Cracks (C): Blister with diameter greater than one inch and/or cracking of coating at the holiday.

Table B.1 Holiday Test Results for Epoxytec CPP Dry-Coated Concrete after 30 Days Immersion (CIGMAT CT-1)

Concrete	Holiday	Medium and Rating (Specimens)		Total No. % (N/B/C)	Remarks
		DI Water	1% H_2SO_4		
Dry	No Holiday	N (2)	N (2)	4 (100/0/0)	Coating color changed in the acid submerged portion
	0.125 in.	N (2)	N (2)	4(100/0/0)	Coating color changed in the acid submerged portion
	0.50 in.	---	N (2)	2 (100/0/0)	Coating color changed in the acid submerged portion
Total No. %(N/B/C)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After 30 days of immersion	100% N	100% N		No visible blisters or cracking; only coating color change noted.

N = No blisters or crack
B = Blister
C = Cracking

Table B.2. Holiday Test Results for Epoxytec CPP Wet-Coated Concrete after 30 Days Immersion (CIGMAT CT-1)

Concrete	Holiday	Medium and Rating (Specimens)		Total No. % (N/B/C)	Remarks
		DI Water	1% H_2SO_4		
Wet	No Holiday	N(2)	N(2)	4 (100/0/0)	Coating color changed in the acid submerged portion
	0.125 in.	N(2)	N(2)	4 (100/0/0)	Coating color changed in the acid submerged portion
	0.50 in.	---	N(2)	2 (100/0/0)	Coating color changed in the acid submerged portion
Total No. %(N/B/C)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After 30 days of immersion	100% N	100% N		No visible blisters or cracking; only coating color change noted.

N = No blisters or crack
B = Blister
C = Cracking

Table B.3. Holiday Test Results for Epoxytec CPP Dry-Coated Concrete after 180 Days Immersion (CIGMAT CT-1)

Concrete	Holiday	Medium and Rating (Specimens)		Total No. % (N/B/C)	Remarks
		DI Water	1% H_2SO_4		
Dry	No Holiday	N(2)	N(2)	4 (100/0/0)	Coating color changed in the acid submerged portion
	0.125 in.	N(2)	N(2)	4 (100/0/0)	Coating color changed in the acid submerged portion
	0.50 in.	---	N(2)	2 (100/0/0)	Coating color changed in the acid submerged portion
Total No. %(N/B/C)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After 180 days of immersion	100% N	100% N		No visible blisters or cracking; only coating color change noted.

N = No blisters or crack
B = Blister
C = Cracking

Table B.4. Holiday Test Results for Epoxytec CPP Wet-Coated Concrete after 180 Days Immersion (CIGMAT CT-1)

Concrete	Holiday	Medium and Rating (Specimens)		Total No. % (N/B/C)	Remarks
		DI Water	1% H_2SO_4		
Wet	No Holiday	N(2)	N(2)	4 (100/0/0)	Coating color changed in the acid submerged portion
	0.125 in.	N(2)	N(2)	4 (100/0/0)	Coating color changed in the acid submerged portion
	0.50 in.	---	N(2)	2 (100/0/0)	Coating color changed in the acid submerged portion
Total No. %(N/B/C)		4 (100/0/0)	6 (100/0/0)	10 (100/0/00)	Total of 10 specimens tested
Remarks	After 180 days of immersion	100% N	100% N		No visible blisters or cracking; only coating color change noted.

N = No blisters or crack;
B = Blister
C = Cracking

Table B5. Holiday Test Results for Epoxytec CPP Dry-Coated Clay Brick after 30 Days Immersion (CIGMAT CT-1)

Clay	Holiday	Medium and Rating (Specimens)		Total No. % (N/B/C)	Remarks
		DI Water	1% H_2SO_4		
Dry	No Holiday	N (2)	N (2)	4 (100/0/0)	Coating color changed in the acid submerged portion
	0.125 in.	N(2)	N(2)	4 (100/0/0)	Coating color changed in the acid submerged portion
	0.50 in.	---	N(2)	2 (100/0/0)	Coating color changed in the acid submerged portion
Total No. %(N/B/C)		4 (100/0/0)	6 (100/0/0)	10 (100/0/6)	Total of 10 specimens tested
Remarks	After 30 days of immersion	100% N	100% N		No visible blisters or cracking; only coating color change noted.

N = No blisters or crack
B = Blister
C = Cracking

Table B6. Holiday Test Results for Epoxytec CPP Wet-Coated Clay Brick after 30 Days Immersion (CIGMAT CT-1)

Clay	Holiday	Medium and Rating (Specimens)		Total No. % (N/B/C)	Remarks
		DI Water	1% H_2SO_4		
Wet	No Holiday	N (2)	N (2)	4 (100/0/0)	Coating color changed in the acid submerged portion
	0.125 in.	N (2)	N (2)	4 (100/0/0)	Coating color changed in the acid submerged portion
	0.50 in.	---	N (2)	2 (100/0/0)	Coating color changed in the acid submerged portion
Total No. %(N/B/C)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After 30 days of immersion	100% N	100% N		No visible blisters or cracking; only coating color change noted.

N = No blisters or crack
B = Blister
C = Cracking

Table B7. Holiday Test Results for Epoxytec CPP Dry-Coated Clay Brick after 180 Days Immersion (CIGMAT CT-1)

Clay	Holiday	Medium and Rating (No. of Specimens)		Total No. % (N/B/C)	Remarks
		DI Water	1% H_2SO_4		
Dry	No Holiday	N (2)	N (2)	4 (100/0/0)	Coating color changed in the acid submerged portion
	0.125 in.	N (2)	N (2)	4 (100/0/0)	Coating color changed in the acid submerged portion
	0.50 in.	---	N (2)	2 (100/0/0)	Coating color changed in the acid submerged portion
Total No. %(N/B/C)		4 (100/0/0)	6 (100/0/0)	10 (100/0/6)	Total of 10 specimens tested
Remarks	After 180 days of immersion	100% N	100% N		No visible blisters or cracking; only coating color change noted.

N = No blisters or crack
B = Blister
C = Cracking

Table B8. Holiday Test Results for Epoxytec CPP Wet-Coated Clay Brick 180 Days Immersion (CIGMAT CT-1)

Clay	Holiday	Medium and Rating (No. of Specimens)		Total No. % (N/B/C)	Remarks
		DI Water	1% H_2SO_4		
Wet	No Holiday	N (2)	N (2)	4 (100/0/0)	Coating color changed in the acid submerged portion
	0.125 in.	N (2)	N (2)	4 (100/0/0)	Coating color changed in the acid submerged portion
	0.50 in.	---	N (2)	2 (100/0/0)	Coating color changed in the acid submerged portion
Total No. %(N/B/C)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After 30 days of immersion	100% N	100% N		No visible blisters or cracking; only coating color change noted.

N = No blisters or crack
B = Blister
C = Cracking

Table B9. Holiday Test Results for Epoxytec CPP Dry-Coated Concrete Brick 180 Days Immersion (CIGMAT CT-1)

Concrete	Holiday	Average weight Change (%)		Remarks
		DI Water	H_2SO_4	
Dry	No Holiday	0.12	0.11	Similar weight change
	0.125 in.	0.24	0.35	Higher weight change in water
	0.50 in.	--	0.44	Higher weight change with increased holiday size
Remarks	After 180 days of immersion	Specimens with holiday showed greater weight change	Specimens with holidays showed greater weight change	Holidays increased the weight change

Table B10. Holiday Test Results for Epoxytec CPP Wet-Coated Concrete Brick after 180 Days Immersion (CIGMAT CT-1)

Concrete	Holiday	Average weight Change (%)		Remarks
		DI Water	H_2SO_4	
Wet	No Holiday	0.25	0.18	Greater weight change in water
	0.125 in.	0.30	0.27	Greater weight change in water
	0.50 in.	--	0.34	Similar weight change with increased holiday size
Remarks	After 180 days of immersion	Specimens with holiday showed greater weight change	Specimens with holidays showed greater weight change	Holidays increased the weight change

Table B11. Holiday Test Results for Epoxytec CPP Dry-Coated Clay Brick after 180 Days Immersion (CIGMAT CT-1)

Clay Brick	Holiday	Average weight Change (%)		Remarks
		DI Water	H_2SO_4	
Dry	No Holiday	0.12	0.20	Greater weight change in acid
	0.125 in.	8.3	8.8	Similar weight change
	0.50 in.	--	9.6	Greater weight change with increased holiday size
Remarks	After 180 days of immersion	Specimens with holiday showed greater weight change	Specimens with holidays showed similar weight change	Greater weight change with larger holidays

Table B12. Holiday Test Results for Epoxytec CPP Wet-Coated Clay Brick after 180 Days Immersion (CIGMAT CT-1)

Clay Brick	Holiday	Average weight Change (%)		Remarks
		DI Water	H_2SO_4	
Wet	No Holiday	0.20	0.44	Greater weight change in acid
	0.125 in.	2.3	2.4	Similar weight change
	0.50 in.	--	1.6	Less weight change with increased holiday size
Remarks	After 180 days of immersion	Specimens with holiday showed greater weight change	Specimens with holidays showed greater weight change	Holidays increased the weight change but the size of holiday did not affect

APPENDIX C

Results and Observations from Bonding Tests

Laboratory Test: Bonding Test
(CIGMAT CT-2, Modified ASTM D4541-85 and
CIGMAT CT-3, Modified ASTM C321-94)
Summary: Tensile Bonding Strength

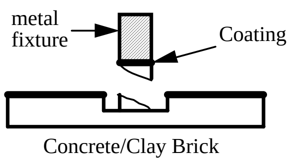
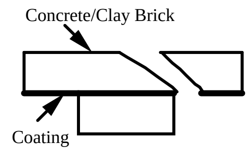
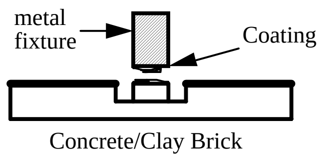
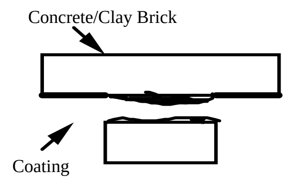
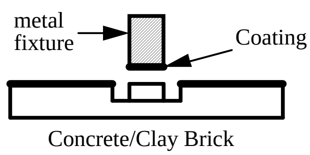
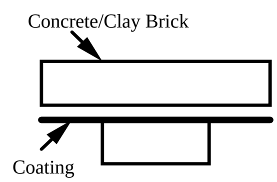
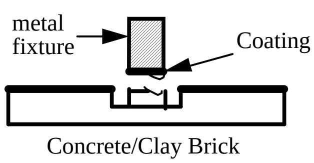
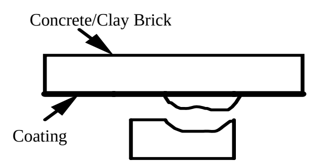
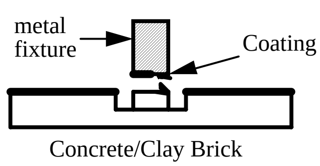
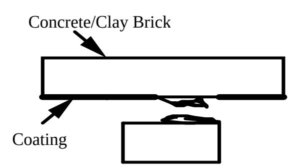
Total CIGMAT CT-2 Tests = 24 **Total CIGMAT CT-3 Tests = 16**

Bonding strengths of coating CPP (dry and wet) with concrete and clay brick were determined according to CIGMAT CT-2 (modified ASTM D4541-85) and CIGMAT CT-3 (modified ASTM C321-94) testing methods. All the coated specimens were cured under water. Both dry and wet specimens were coated to simulate the various field conditions. Performance of Coating CPP was evaluated starting March 2009 and the results are included in this report. A total of 24 bonding tests with concrete specimens and 24 with clay brick specimens was performed.

Failure Types

All the failure types encountered in the bonding tests (modified ASTM D 4541 and ASTM C 321) are listed in Table C1. Type-1 failure is substrate failure (Table C1). This is the most desirable result if the bonding strength is quite high (in the range 8% to 12% of the concrete substrate compressive strength). In Type-2 failure (Table C1), the coating has failed. Type-3 failure is bonding failure where failure occurred between the coating and substrate. Type-4 and Type-5 are combined failures. Type-4 failure is the bonding and substrate failure where the failure occurs in the substrate and on the interface of the coating and the substrate. This indicates that the adhesive strength is comparable with the tensile strength of substrate. Type-5 failure (Table C1) is coating and bonding failure where the failure occurs due to low cohesive and adhesive strength of the coating.

Table C1. Failure Types of Modified ASTM D 4541 Test and ASTM C 321 Test

Failure Type	Description	CIGMAT CT-2 Test (Modified ASTM D 4541)	CIGMAT CT-3 Test (Modified ASTM C 321)
Type-1	Substrate Failure		
Type-2	Coating Failure		
Type-3	Bonding Failure		
Type-4	Bonding and Substrate Failure		
Type-5	Bonding and Coating Failure		

CPP (Dry Coating)

(i) Concrete

CIGMAT CT-2 (modified ASTM D 4541-85): A total of eight laboratory tests were performed. All failures were Type-1. The average bonding strength from all the tests performed was 190 psi (1.3 MPa) (Table C2).

CIGMAT CT-3 (modified ASTM C 321-94): A total of four tests was performed. Test results are summarized in Table C6. Type-1 (75%) and Type-4 (25%) failures were observed. Average bonding strength from all the laboratory tests was 255 psi (1.8 MPa) (Table C6).

Summary: The type of test influenced the mode of failure and the bonding strength. Type-1 failures were observed during the pull-off test (CIGMAT CT-2), while the sandwich test (CIGMAT CT-3) produced Type-1 and Type-4 failures. The average bonding strength from CIGMAT CT-2 tests was 190 psi (1.3 MPa) and from CIGMAT CT-3 tests was 255 psi (1.8 MPa). The average tensile bonding strength with dry concrete was 212 psi (1.5 MPa), ranging from 153 to 280 psi, with 92% being substrate (Type-1) failures.

(ii) Clay Brick

CIGMAT CT-2 (modified ASTM D 4541-85): A total of eight tests was performed. All were Type-1 failures. The average bonding strength from all the tests was 251 psi (1.7 MPa) (Table C5).

CIGMAT CT-3 (modified ASTM C 321-94): A total of four tests was performed. Type-1 (50%) and Type-5 (50%) failures were observed in the test. Test results are summarized in Table C8. The average bonding strength from all tests was 286 psi (2.0 MPa) (Table C8).

Summary: The type of test influenced the mode of failure and the bonding strength. Type-1 failure was observed during the pull-off test (CIGMAT CT-2), while the sandwich test (CIGMAT CT-3) produced Type-1 and Type-5 failures. The average bonding strength from CIGMAT CT-2 tests was 251 psi (1.7 MPa) and from CIGMAT CT-3 tests was 286 psi (2.0 MPa). The average tensile bonding strength with dry clay brick was 262 psi (1.8 MPa), ranging from 190 to 309 psi, with 83% Type-1 failures in the clay brick substrate.

CPP (Wet Coating)

(i) Concrete

CIGMAT CT-2 (modified ASTM D 4541-85): A total of eight tests was performed. All were Type-3 failures. The average bonding strength from all the tests was 142 psi (1.0 MPa) (Table C3).

CIGMAT CT-3 (modified ASTM C 321-94): A total of four tests was performed. All were Type-5 failures. Test results are summarized in Table C7. The average bonding strength from all the laboratory tests was 204 psi (1.4 MPa) (Table C7).

Summary: The type of test influenced the bonding strength but not the failure type. The average bonding strength from the pull-off test (CIGMAT CT-2) was 142 psi (1.0 MPa), and from the sandwich test (CIGMAT CT-3) was 204 psi (1.4 MPa). The average tensile bonding strength for wet concrete was 163 psi (1.1 MPa), ranging from 92 to 236 psi, with 67% bonding (Type-3) and 33% bonding and coating (Type-5) failures.

(ii) Clay Brick

CIGMAT CT-2 (modified ASTM D 4541-85): A total of eight tests was performed. The observed failures included six Type-1 (75%) and two Type-4 (25%) failures. The average bonding strength from all the tests was 282 psi (1.9 MPa) (Table C5).

CIGMAT CT-3 (modified ASTM C 321-94): A total of four tests was performed. Type-1 (50%) and Type-5 (50%) failures were observed. Test results are summarized in Table C9. The average bonding strength from all the tests was 295 psi (2.0 MPa) (Table C9).

Summary: The type of test influenced the bonding strength and not the dominant type of failure. The average bonding strength from the pull-off test (CIGMAT CT-2) was 282 psi (1.9 MPa) and from the sandwich test (CIGMAT CT-3) was 295 psi (2.0 MPa). The average tensile bonding strength with wet clay brick was 286 psi (2.0 MPa), ranging from 184 to 342 psi, with three types of failure modes - 67% substrate (Type-1), 16.6% bonding and substrate (Type-4) and (16.6%) bonding and coating (Type-5) failures.

Table C2. Bonding Strength of Epoxytec CPP with Dry Concrete CIGMAT CT-2 (Pull-Off)

Concrete	Approximate Curing Time (days)	Failure Modes					Average Failure Strength (psi)
		Type-1	Type-2	Type-3	Type-4	Type-5	
Dry	30	××××					160
	90	××					212
	180	××					228
Total No. (% Failure)		8 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	Total of 8 tests.
Remarks	Up to 180 days	Good bonding strength	None	None	None	None	Types-1 failure; average bonding strength for all tests – 190 psi (1.3 MPa).

Type-1 = Concrete failure
Type-2 = Coating failure
Type-3 = Bonding failure
Type-4 = Combined concrete and bonding failure
Type-5 = Combined coating and bonding failure

Table C3. Bonding Strength of Epoxytec CPP with Wet Concrete CIGMAT CT-2 (Pull-off)

Concrete	Approximate Curing Time (days)	Failure Modes					Average Failure Strength (psi)
		Type-1	Type-2	Type-3	Type-4	Type-5	
Wet	30			××××			95
	90			××			157
	180			××			223
Total No. (% Failure)		0 (0%)	0 (0%)	8 (100%)	0 (0%)	0 (0%)	Total of 8 tests.
Remarks	Up to 180 days	None	None	None	None	None	Type-3 failure; average bonding strength for all tests – 142 psi (1.0 MPa).

Type-1 = Concrete failure
Type-2 = Coating failure
Type-3 = Bonding failure
Type-4 = Combined concrete and bonding failure
Type-5 = Combined coating and bonding failure

Table C4. Bonding Strength of Epoxytec CPP with Dry Clay Brick CIGMAT CT-2 (Pull-off)

Clay	Approximate Curing Time (days)	Failure Modes					Average Failure Strength (psi)
		Type-1	Type-2	Type-3	Type-4	Type-5	
Dry	30	××××					236
	90	××					256
	180	××					276
Total No. (% Failure)		8 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	Total of 8 tests.
Remarks	Up to 180 days	Good bonding strength	None	None	None	None	Type-1 failure; average bonding strength for all tests – 251 psi (1.7 MPa).

Type-1 = Concrete failure
Type-2 = Coating failure
Type-3 = Bonding failure
Type-4 = Combined concrete and bonding failure
Type-5 = Combined coating and bonding failure

Table C5. Bonding Strength of Epoxytec CPP with Wet Clay Brick CIGMAT CT-2 (Pull-off)

Clay Brick	Approximate Curing Time (days)	Failure Modes					Average Failure Strength (psi)
		Type-1	Type-2	Type-3	Type-4	Type-5	
Wet	21	××			××		251
	90	××					309
	180	××					315
Total No. (% Failure)		6 (75%)	0 (0%)	0 (0%)	2 (25%)	0 (0%)	Total of 8 tests.
Remarks	Up to 180 days	Good bonding strength	None	None	None	None	Type-1 and Type-4 failures; average bonding strength – 282 psi (1.9 MPa).

Type-1 = Concrete failure
Type-2 = Coating failure
Type-3 = Bonding failure
Type-4 = Combined concrete and bonding failure
Type-5 = Combined coating and bonding failure

Table C6. Bonding Strength of Epoxytec CPP with Dry Concrete CIGMAT CT-3 (Sandwich)

Concrete	Approximate Curing Time (days)	Failure Modes					Average Failure Strength (psi)
		Type-1	Type-2	Type-3	Type-4	Type-5	
Dry	30	×			×		260
	90	×					218
	180	×					280
Total No. (% Failure)		3 (75%)	0 (0%)	0 (0%)	1 (25%)	0 (0%)	Total of 4 tests.
Remarks	Up to 180 days	Good bonding strength	None	None	None	None	Type-1 and Type-4 failures; average bonding strength – 255 psi (1.8 MPa).

Type-1 = Concrete failure
Type-2 = Coating failure
Type-3 = Bonding failure
Type-4 = Combined concrete and bonding failure
Type-5 = Combined coating and bonding failure

Table C7. Bonding Strength of Epoxytec CPP with Wet Concrete CIGMAT CT-3 (Sandwich)

Concrete	Approximate Curing Time (days)	Failure Modes					Average Failure Strength (psi)
		Type-1	Type-2	Type-3	Type-4	Type-5	
Wet	30					××	196
	90					×	192
	180					×	235
Total No. (% Failure)		0 (0%)	0 (0%)	0 (0%)	0 (0%)	4 (100%)	Total of 4 tests.
Remarks	Up to 180 days	None	None	None	None	None	Type-5 failures; average bonding strength – 204 psi (1.4 MPa).

Type-1 = Concrete failure
Type-2 = Coating failure
Type-3 = Bonding failure
Type-4 = Combined concrete and bonding failure
Type-5 = Combined coating and bonding failure

Table C8. Bonding Strength of Epoxytec CPP with Dry Clay Brick CIGMAT CT-3 (Sandwich)

Clay Brick	Approximate Curing Time (days)	Failure Modes					Average Failure Strength (psi)
		Type-1	Type-2	Type-3	Type-4	Type-5	
Dry	30	×				×	298
	90	×					238
	180					×	309
Total No. (% Failure)		2 (50%)	0 (0%)	0 (0%)	0 (0%)	2 (50%)	Total of 4 tests.
Remarks	Up to 180 days	Good bonding strength	None	None	None	None	Type-1 and Type-5 failures; average bonding strength – 286 psi (2.0 MPa).

Type-1 = Concrete failure
Type-2 = Coating failure
Type-3 = Bonding failure
Type-4 = Combined concrete and bonding failure
Type-5 = Combined coating and bonding failure

Table C9. Bonding Strength of Epoxytec CPP with Wet Clay Brick CIGMAT CT-3 (Sandwich)

Clay Brick	Approximate Curing Time (days)	Failure Modes					Average Failure Strength (psi)
		Type-1	Type-2	Type-3	Type-4	Type-5	
Wet	21	×				×	276
	90	×					308
	180					×	318
Total No. (% Failure)		2 (50%)	0 (0%)	0 (0%)	0 (0%)	2 (50%)	Total of 4 tests.
Remarks	Up to 180 days	Good bonding strength	None	None	None	None	Type-1 and Type-5 failures; average bonding strength – 295 psi (2.0 MPa).

Type-1 = Concrete failure
Type-2 = Coating failure
Type-3 = Bonding failure
Type-4 = Combined concrete and bonding failure
Type-5 = Combined coating and bonding failure

APPENDIX D

Manufacturer Data Sheet for CPP RC3

VENDOR DATA SHEET
PHYSICAL PROPERTIES OF COATING

Coating Product Name: CPP RC3
Coating Product Vendor Name and Address: **Epoxytec International Inc.**
P.O. Box 3656
West Park, FL 33083
Coating Type: Epoxy (CPP-Concrete Polymer Paste)

Testing Method	Vendor Results
Tensile Adhesion to Concrete (ASTM D 4541)	Substrate failure
Chemical Resistance (ASTM D 543) (3 % $H_2 SO_4$)	Hydrogen sulfide, mild acids
Water Vapor Transmission (ASTM D 1653/E 1907)	0
Bending Strength or Tensile Strength (ASTM D 790)	8,900 psi
Hardness- Shore D (ASTM D 2240)	82
Impact Resistance (ASTM G 14)	N.A.
Volatile Organic Compounds - VOCs (ASTM D 2832)	None

Worker Safety	Result/Requirement
Flammability Rating	Unknown
Known Carcinogenic Content	None
Other hazards (corrosive)	Corrosive in uncured state (B component only)

Environmental Characteristics	Result/Requirement
Heavy Metal Content (w/w)	None
Leaching of Cured Coating (TCLP)	None
Disposal of Cured Coating	Non-hazardous solid waste

Application Characteristics	Result/Requirement
Primer Requirement	None
Number of Coats and Thickness	One coat maximum 0.75 in.
Minimum Application Temperature	40º F
Minimum Cure Time Before Handling	2 hrs at 77º F (25º C)
Maximum Application Temperature	115º F
Minimum Cure Time before Immersion into Service	3 hrs at 77º F (25º C)
Type of Surface Preparation Before Coating	Clean substrate, water pressure 3000 psi

Vendor Experience	Comments
Length of Time the Coating in Use	20 years
Applicator Training & Qualification Program	Certified applicators
QA/QC Program for Coating/Lining	Certified applicators

N.A. – Not provided by vendor or not applicable.